THE NATION'S FOOD

A Survey of Scientific Data

Edited for the Society of Chemical Industry (Food Group) by

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and

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With an Introduction by

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VI	*Chem. and Ind.*, 1940, 735.
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XXVII	*Ibid.*, 439.

EDITORS' PREFACE

In this book an attempt has been made by thirty-two scientists to bring together in as convenient a form as possible the knowledge at present available about the physical and chemical characteristics of the foods eaten in Great Britain, always with special reference to the nutritional value of those foods, rather than to their properties as marketable commercial products. The biological background has, it is hoped, been adequately filled in whenever this was relevant to the main theme of the book, and it has been the Editors' endeavour (as it was of those who arranged the meetings at which the matter of this book was first presented) to preserve a judicious balance between attention to the proximate principles—fat, protein and carbohydrate—and study of those accessory factors, minerals and vitamins, that figure so extensively in the "newer knowledge of nutrition."

It will be found that this book can in many parts be read by those with no detailed technical knowledge of food chemistry or technology, though it has been the desire of authors and editors alike to include all recent knowledge that is solidly based on valid experimental work, wherever this knowledge helps to evaluate the position of any particular food in our national dietary. The book is thus, at one and the same time, intended for the specialist and for those with a wide general interest in the problems of feeding for optimum health : in this dual aspect it mirrors the FOOD GROUP that has had the primary responsibility for its production. It seems to us permissible here to give some short account of the GROUP—its origin, its objects and its activities.

When the SOCIETY OF CHEMICAL INDUSTRY was founded in 1881, and when it was later incorporated by Royal Charter in 1907, an unknown proportion of its members were directly or indirectly concerned with food technology, that is, with the growing application of scientific knowledge, and particularly of chemistry, to the problems of producing, processing, preserving and transporting food for human and animal consumption.

The SOCIETY is very largely, though not exclusively, composed of qualified research, analytical and works chemists and chemical engineers; it tries to do for general industrial chemistry what other societies do for fundamental chemistry in the organic, inorganic and physical fields or for one or other of the highly specialized branches of chemistry, such as analysis, metallurgy, biochemistry, dyeing, brewing, soils, paints and so on. The SOCIETY has naturally a considerable membership in common with related learned societies, and it makes this informal contact more effective by the frequent arrangement of joint meetings with one or other of the many organizations whose territories march with its own.

In spite of the opportunities thereby afforded to members of the SOCIETY for some degree of specialization within its broad ranks, the need for an occasional concentration of interest made itself increasingly felt during the period between the two world wars. One group of members that had been particularly active in the SOCIETY'S general affairs, yet was amongst the most insistent in its request for closer attention to its own problems as well, was the now large number engaged in the various sections of the British food industry. Accordingly in 1932, the SOCIETY'S FOOD GROUP was formed. Under the initial chairmanship of Dr. Leslie H. Lampitt, it had an instantaneous success. At the time of writing this Preface, the GROUP is in its twelfth year and has over 800 members. At present there is no subscription other than the annual subscription to the SOCIETY, of which any member can join the GROUP by intimating that he wants to. Only members of the SOCIETY can join the GROUP.

As the GROUP grew in numbers and extended its activities, it became clear that an increasing proportion of its members were interesting themselves in the nutritional properties of the materials that they and their colleagues of the food industry were handling or might be called upon to handle. To meet this interest without the risk of causing disintegration of a GROUP that had already had, and was certain to continue having, a completely successful life, it was decided to establish within the GROUP a NUTRITION PANEL (a Microbiological Panel had been successfully begun within the GROUP a few months earlier), and this new PANEL was formed during the Session 1937–38. Here again membership was freely open to members of the FOOD GROUP, but only to them.

The NUTRITION PANEL, like the Microbiological Panel and the FOOD GROUP itself, had for its main function the organizing of meetings for the reading of scientific papers that could, if found suitable, be published in one of the SOCIETY'S journals. The PANEL did not, however, neglect the social aspects of its activities, in this matter again following the practice of the GROUP and the parent SOCIETY. After September, 1939, it was inevitable that the whole question of the PANEL'S policy in the immediate future should come up for careful consideration by the Committees of both PANEL and GROUP.

It must be borne in mind that the scientific meetings of the PANEL had during its first year been arranged on subjects more likely to interest the members of the PANEL itself than the other members of the GROUP, whose non-membership of the PANEL was taken to indicate that they did not consider themselves at any rate primarily concerned with the nutritional aspects of food technology. The PANEL Committee, sitting in the autumn of 1939, found itself unanimous on two matters: first, that its meetings and other activities should, as far as circumstances would permit, continue during the war, and secondly that it must orientate its activities as much as possible to consideration of problems arising out of war conditions. These decisions, fully endorsed by the FOOD GROUP Committee, received practical expression by the inauguration and completion of the series of meetings on "The Nation's Food" and by their continuation through even the worst periods of the 1940–41 air attack on London.

In a number of ways these meetings differed from those encouraged as normal to the PANEL'S activities before the war. They were not merely "domestic" meetings arranged primarily for, and attended almost only by, members of the PANEL: they were, on the contrary, officially described as "arranged for the FOOD GROUP by its NUTRITION PANEL" and had the full authority of the GROUP itself. Again, the individual contributors were not left free to write on any germane subject chosen by themselves: they were invited by the meetings' organizers specifically to survey an allocated corner of the field, the field itself having in advance been carefully assigned its group of crops and other food products by the PANEL Committee. In other words, these were "planned" meetings, all seven of them, and to them were invited as authoritative exponents not only food chemists, but biologists, field workers in nutrition, dieticians and bacteriologists. Six of the meetings were organized by the FOOD GROUP itself: the seventh was held jointly with the Nutrition Society, Chapters XXVI and XXVII being revisions of two out of the four papers read at that joint meeting.

It had always been intended by the PANEL and GROUP Committees, and their intention was known and approved by the Council of the SOCIETY, to arrange for publication in book form of the papers read at this series of meetings. Pressure of war-time work has made it impossible for contributors and editors alike to revise these papers as rapidly, or even as completely, as could have been wished, and other delays have also held matters up. Nevertheless, it is our belief and hope that this book may to some extent justify the description, now well-nigh decrepit with overwork, of "unique." It is meant to serve the needs of the wide and growing circles of scientific men and women—including many of our medical colleagues and their "auxiliaries"—who need up-to-date, objective, critical information about the physical, chemical and physiological properties of the food we eat.

We cannot even begin adequately to acknowledge the help we have received from many sources in preparing this book for publication. The authors of the papers have without exception readily given permission for their contributions to appear in this book without any kind of financial benefit to themselves. Again, all of them have been at pains, and some at very great pains, to revise their original papers in the light of detected errors and subsequent knowledge. Contributions to this book have been made by individual specialists and by members of the technical staffs of Government Departments, Research Institutions and industrial laboratories, including Ministry of Agriculture and Fisheries; Cereals Research Laboratory, Ministry of Food; Low Temperature Research Station and Torry Research Station (Department of Scientific and Industrial Research); Dunn Nutritional Laboratory (Cambridge University and Medical Research Council); Lister Institute of Preventive Medicine; National Institute for Research in Dairying; University of Bristol Research Station, Camden; School of Agriculture, Cambridge University; Glasgow College of Domestic Science; Beatties Bakeries, Ltd.; British Arkady Co., Ltd.; Chivers & Sons, Ltd.; Glaxo Laboratories, Ltd.; J. Lyons & Co., Ltd.; Vitamins, Ltd. For the willingness with which all of these have extended "permission to publish", previously granted for the papers appearing in the SOCIETY'S Journals, to cover their revision and inclusion in "The Nation's Food," we would express our thanks, which are even more cordially offered to the various contributors themselves.

As a matter of historical interest we have included at the end of the table of CONTENTS the complete bibliographical references to the papers as originally published after they had been read at FOOD GROUP meetings.

The index has been compiled by Miss M. LePla of the Bureau of Abstracts. We are greatly indebted to her for carrying out this irksome but essential task with her customary skill and patience and we wish also to thank the Bureau for allowing her to undertake the work.

The Chairman of the SOCIETY'S Publications Committee, Mr. F. P. Dunn, has been, as we have by now learnt to expect with complete confidence, a tower of strength in all technical matters appertaining to printing and publishing and was in no small measure responsible for convincing his Committee and the Council that this book should be published, as soon as possible and *in extenso.* Finally, we have to express our thanks both to that Committee and to the Council for having appointed us as Honorary Editors to what we consider a book so valuable that to edit it is an honour, and also for having left us complete discretion as to how we did the job. In particular, they have let us write this Preface, which is entirely ours and in no sense to be laid at their door.

A. L. BACHARACH
T. RENDLE

INTRODUCTION

Out of the forty-five or more millions of persons in this country, perhaps one in ten carries out some sort of culinary process daily. If one in a hundred of these has some desire to cater or cook intelligently, the present book will have forty-five thousand readers. Not that all the forty-five thousand will read all the book, for the contents are not all intended to appeal to the same constituency; to quote the Editor's preface, "the book is thus at one and the same time intended for the specialist and for those with a wide general interest in the problems of feeding for optimum health." The latter category, whilst it should include the entire community of caterers and cooks, is not confined to these; doctors emphatically should be among the readers of the book, and perhaps less emphatically, farmers and market gardeners. Lastly, there is the general public, in which category I venture to include myself. When, as an ex-professor of physiology who had specialised in respiration, I had the Chairmanship of the Food Investigation Board thrust upon me, I would have given much to have had such a book as the present. I found myself in a world quite new to me; one in which new vitamins appeared almost to breed, so fast did they come. What were they? What was their importance? What foods contained them and in what quantities? To what extent were they destroyed by keeping or by cooking? Nor are questions of this character confined to the vitamins. They are extending to the basal constituents of food—what, in my student days, were called the proximate principles—proteins, carbohydrates, fats, salts and water. Now we are asking, what is the biological value of this or that protein? What is meant by "biological value"? What are the relative nutritive values of animal and vegetable proteins? And the like and other questions are arising about fats. How far do we take them for their own sakes and how far for the sake of the vitamins which they hold in solution. How are they to be preserved from going rancid? And what does "rancidity " mean? Then there are the salts: in old days they were taken for granted, now we talk about "iron deficiencies" and "calcium deficiencies," whilst we see "magnesium deficiencies" and "cobalt deficiencies" peeping up over the horizon. Nor is that all; we become interested not only in obtaining a sufficiency of individual inorganic elements, but in their relation to one another, as, for instance, the phosphorus-calcium ratio. On what dietaries must we rely for the appropriate salts in the appropriate proportions?

All these questions and many more are answered in "The Nation's Food." The specialist will discover that they are answered exhaustively; the amateur will have no difficulty in following many of the chapters. Some of these deal with matter not only non-technical, but indeed at least two removes away from the technical appraisement of articles of diet. Such chapters are none the less full of interest; take, for instance, those on the Biology of Sea Fisheries and The Planning of Vegetable Production respectively. There is an open-air tang about each of these and they are both worth much deliberation. In a specialised world we sometimes forget what Agriculture is or should be. We think of it as a vocation, as a means of providing an income for perhaps the most important single section of the population. Not at all: it is that, but it is much more, it is the science of how to get the most benefit for the nation as a whole from a given acreage. Agriculture, properly viewed, commences with the soil and ends with the supper table. Nor is the case very different with fisheries. Man has at his disposal the ocean; how is he to make the most of it in terms of food?

To complete such knowledge you must know about the micro-organisms in the sea, about the effect of sunlight on them, about the extent to which you can fish the surface or the bed of the ocean without over-fishing it; you must know how to transport the fish without prejudice to its nutritive value; you must know what that nutritive value is and how to preserve it when the fish is subjected to cooking; and last, but not least, how to serve it so that it will be eaten.

The same is true of the fruits of the earth. You may eat them as such or you may convert them into milk or eggs or pork or beef, as vehicles for first-class protein. But the scope of knowledge necessary for the nutrition of the population from the products of the land is no smaller in its expanse, and is even more complicated, than that of the products of the sea. It begins with soil analysis and treatment. It ends with human psychology—for uneaten food has no nutritive value. This fact I would commend especially to doctors and hospital caterers.

So I come to ask myself the question—how much concerning food and diet still remains to be discovered? In this book the reader will find something about most of the topics on which I have touched; its contents are very largely the fruits of discoveries which have taken place within the present century. Yet it contains also some which suggest that the task is not yet complete. There is the melancholy case of asparagus, seakale, celery and onions, which I gather from the pages of the book have little or no nutritive value. I will end with a remark made to me by Sir Jack Drummond, "It is singular that onions, or plants of the onion family, should be regarded almost all over the world as staple articles of diet if, in fact, they contribute nothing to nutrition. I cannot but think that there are still things to be found out."

JOSEPH BARCROFT

Cambridge
June, 1945

Part I

THE EGG AS FOOD

(*Papers read at a meeting on 24th April,* 1940)

CHAPTER I

THE BIOLOGICAL POSITION OF THE BIRD'S EGG

By JOSEPH NEEDHAM, F.R.S.

In the eggs of terrestrial vertebrates the mechanisms for the protection and nutriment of the embryo have attained the highest degree of complexity, falling short only of viviparous adaptations. The simplest kind of eggs are those of marine invertebrates, such as the sea-urchin, where cleavage is holoblastic (because the cell contains so little yolk) and equal (for the resulting cells are roughly of the same size). Since the period of development is very short, the egg is small. In the eggs of lower vertebrates, such as the newt, cleavage is holoblastic but unequal (because yolk accumulated at the vegetal pole impedes the cleavage process). Such eggs are protected mainly by gelatinous coverings. But in the eggs of higher vertebrates, such as the fowl, inert yolky material has accumulated to such extent that the protoplasmic part, which actually cleaves into daughter-cells, occupies only a small discoidal area on the "egg-cell's" surface. Since only a part undergoes cell-division, this kind of development is called meroblastic. The egg-white surrounding the egg-cell is the evolutionary successor of the amphibian egg-jelly.

Primitive animals developing in the sea relied upon it, and still do rely upon it, as a source of the building-materials, the ash and water. Even the octopus embryo is not supplied by its mother with more than a small quota of the copper that it will need to make the amount of essential blood-pigment, haemocyanin, with which it will hatch. Animals developing in fresh-water, such as the newt or frog, still depend absolutely upon their environment for water. But when the first terrestrial egg was invented, some mechanism was needed to conserve water, and hence the egg-shells of the sauropsida. In the hen's egg there is just enough water to construct one embryo and to evaporate through the shell during the process, provided the external environment is not immoderately dry. The hen's egg, indeed, represents to perfection the "closed-box" (cleidoic) type of development to which terrestrial ovipara had to have recourse. It is probable that this type of development involved several important metabolic adjustments such as: (1) reduction of protein catabolism and intensification of fat catabolism; (2) the invention of uricotelic nitrogenous catabolism; and (3) development of special resistance to ketosis; as well as (4) adaptively accelerated incubation time.

In structure and constitution the yolk of the bird's egg is richer in fat than protein, of acid *p*H and low water-content, while the white's solid is almost wholly protein, in a medium of alkaline *p*H and high water-content; the structure of both yolk and white are complex.

CHAPTER II

THE CHEMICAL COMPOSITION OF THE EGG

By E. M. Cruickshank

The efficiency of the hen as a physiological machine.—The original jungle fowl laid only 20 to 26 eggs a year, but by selective breeding we have been able to obtain much higher levels of productivity, and hens laying 250 eggs a year are now quite common. The hen has therefore become a highly specialized machine for the conversion of raw materials into human foodstuffs, and her efficiency in this respect is greater than that of any other farm animal except the milch cow. A hen laying 250 eggs a year will manufacture and pack 31 lb. of a finished product, though she herself may weigh only 4 lb. This product will contain, in addition to vitamins and minerals, 4·1 lb. of protein and 3·3 lb. of fat, while the packing consists of about 3 lb. of calcium carbonate in the form of shell. As an efficient producer of one of our most valuable "protective" foods, the hen deserves an important place in our agricultural economy.

Size and relative composition of the egg.—Eggs vary considerably in size, depending in large measure on the breed of the hen, the heavier breeds tending to lay the larger eggs. A small egg may weigh as little as 40 g.; a large one as much as 70 g. An average-sized egg weighs 56 g., i.e., approximately 2 oz., of which the shell constitutes 11 per cent., the white 58 per cent., and the yolk 31 per cent. These proportions do not vary to any great extent, no matter what the size of egg. The percentage composition of the edible portion of the egg is as follows:

Whole egg: edible portion

	Per cent.
Water	73·7
Protein	13·4
Fat	10·5
Ash	1·0

Contrary to popular belief, high egg production has no detrimental effect on the size or quality of the egg, except for the vitamin A content, which may become somewhat reduced towards the end of a prolonged laying season. In many respects, the eggs laid by high-producing hens are better than those laid by low producers. The properties included under the term quality are frequently characteristic of the eggs of individual birds, and are influenced mainly by genetic factors.

The shell.—The shell contains the following constituents:

Composition of egg shell

	Per cent.
Calcium carbonate	93·7
Magnesium carbonate	1·39
Phosphorus (P_2O_5)	0·76
Organic matter	4·15

These figures show that the main constituent is carbonate of lime, other elements occurring only in small quantities. The organic matter is found in the very thin cuticle covering the shell, but it is also present in the mineral portion, where it forms a matrix in which the inorganic salts are imbedded. On the inner side of the shell, and enclosing the yolk and white, are paper-like structures, the shell membranes, which consist of keratin, a protein also present in human skin.

Shell colour.—The colour of the shell may vary from white to a pale coffee shade, its pigmentation being due to the presence of porphyrin, an organic compound related to the haemoglobin of the blood. The depth of the colour is dependent entirely on the breed of the hen, and is no guide to the interior quality of the egg.

The white.—The white contains a high proportion of water, since it acts as the principal reservoir of water for the embryonic chick. Its main organic constituent is protein. Small amounts of salts are also present, along with traces of fat, and about ½ per cent. of carbohydrate. The following figures for the composition of whole fresh egg, white and yolk have been published in the United States Department of Agriculture Circular, No. 549:

	Whole egg: edible portion per cent.	Egg white per cent.	Egg yolk per cent.
Water	74·0	87·8	49·4
Protein	12·8	10·8	16·3
Fat	11·5	—	31·9
Total carbohydrate	1·0	—	—
Ash	1·0	0·6	1·7

The white is separable into at least three parts; an outer layer of fluid or thin white, an inner layer of firm or thick white and an inner layer of fluid white which surrounds the yolk. It is the layer of firm white which stands up around the yolk when a fresh egg is broken out on to a flat surface.

Properties of thick and thin white.—Individual eggs may vary considerably in the ratio of thick to thin white that they contain.

At one time this variation was attributed to the diet, but it is now established that the percentage of thick white present is characteristic of the individual hen, and is determined largely by the histological structure of the albumen-secreting cells of the oviduct.[1] Besides differing in physical properties, the layers of thick and thin white differ also in chemical constitution, the former containing a higher percentage of ovomucin than the latter.[2]

From the culinary point of view, the proportion of thick to thin white present is of considerable significance. For frying or poaching, an egg with a large percentage of thick white is desirable, since in this case, the white, when the egg is broken out into the pan, will stand up closely round the yolk, and the egg coagulates in a small firm mass instead of spreading over the frying pan or into the poaching water. The capacity of forming a stiff froth when beaten is, however, similar in both thick and thin white. Indeed, the thin white when beaten produces a slightly greater volume than does the thick white, and therefore for certain purposes eggs (that is, fresh eggs) with a high percentage of thin white are equal to, or even better than, those having much thick white.[3]

The yolk.—The yolk differs greatly in composition from the white, since its function is to provide a supply of nutritive and building material for the developing chick. It contains much less water and more solid materials, among the latter being a large proportion of fat. It is also well fortified with vitamins and mineral constituents, but contains little or no carbohydrate. Fresh egg yolk has the following composition:

COMPOSITION OF FRESH YOLK

	Per cent.
Water..	49·0
Fat	31·6
Protein	16·7
Ash	1·5

Yolk colour.—The colour of the yolk is very variable, and may range from palest yellow to deep orange. The chief colouring matter is xanthophyll, a pigment also present in yellow maize and green plants. Carotene gives butter its yellow colour and occurs along with cryptoxanthine, but these two substances are present only in small amounts. The depth of colour is roughly proportional to the xanthophyll content which, as we shall see later, is regulated mainly by the bird's diet.

PROTEIN CONTENT OF WHITE AND YOLK

Protein content of the white.—The egg white or egg albumin is not a single substance, but is composed of five different proteins, of which one, ovalbumin, constitutes about 70 per cent. of the total. The others present are ovoglobulin, ovomucin, conalbumin, and ovomucoid. A protein is composed of about twenty simpler nitrogenous compounds, the amino-acids, which differ in chemical composition and nutritive function. Whereas many of them can by synthesized in the animal body, with others this cannot be done, and they must therefore be supplied in the food consumed. The amino-acids nutritionally essential to man need not be enumerated here, but all of them occur in the proteins of the egg white.

Protein content of the yolk.—The protein content of the yolk is relatively high, and is composed mainly of the two proteins, vitellin and levitin, in the proportion of approximately 4:1. Vitellin belongs to the group of phosphoproteins, and its phosphorus constitutes about one-third of the total phosphorus in the yolk.[4] In contrast to vitellin, levitin contains little phosphorus, but it has a relatively high percentage of sulphur, which accounts for a considerable proportion of the entire sulphur content of the yolk, about half being present in levitin.[5] These two proteins contain notable amounts of the amino-acids cystine, tryptophan, tyrosine and lysine, a fact which is probably of significance in the nutrition of the developing chick.

Fat content of the yolk.—All the fat of the egg, except for traces which occur in the white, is concentrated in the yolk, where it is present in the form of an emulsion. The yolk is rich in fat (ether extract), about 30 per cent. to 32 per cent. being present in the fresh or 62 per cent. in the dried yolk.

The fats of the egg are of complex chemical structure, and consist of two types: (1) neutral fats or glycerides and (2) phosphorized fats or lecithins. The neutral fats are compounds containing fatty acids and glycerol and are of the type found in beef, mutton, and other body fats. The lecithins contain, in addition to fatty acids, both nitrogen and phosphorus. These lecithins are found in certain body tissues such as brain, liver, and pancreas, but adipose tissue contains only insignificant amounts. In the yolk lecithins are present to the extent of probably 10 per cent., and the egg, therefore, is richer in this respect than most other fats in human diet. The function of the lecithins in nutrition is not yet clearly understood, but there is reason to believe that they are of considerable importance in fat metabolism, and they are probably essential also for the normal structure and functioning of the body. In the developing chick the phosphorus of the lecithins is utilized in the formation of bone.

The fatty acids present in the yolk are palmitic and stearic acid (which together form about 31 per cent. of the total), oleic acid (46 per cent. to 51 per cent.), linolic acid (15 per cent. to 19 per cent.) and linolenic acid (2 per cent. to 3 per cent.). Other acids of a highly unsaturated nature, such as arachidonic acid, also occur in small quantities, probably as part of the lecithin.

Cholesterol content of the yolk.—Another constituent of the ether extract of the yolk is cholesterol, which occurs both free and in chemical combination with the fatty acids. One egg yolk contains about 200 to 300 mg. of this compound, which is derived in part from the food, and in part from synthesis by the hen during the process of yolk formation. Its presence is of interest because of the fact that it is closely associated with vitamin D.

Mineral content of white and yolk.—According to Rose and Vahlteich[6] the more important minerals and their distribution in the egg are as follows:

THE MINERAL COMPOSITION OF THE EDIBLE PORTION OF THE EGG

	Whole egg	Egg yolk	Egg white
Calcium, per cent.	0·06	0·13	0·01
Chlorine, per cent.	0·13	0·10	0·15
Copper, parts per million	1·87	4·15	0·85
Iodine, parts per million	0·1	—	—
Iron, per cent.	0·003	0·0086	0·0001
Magnesium, per cent.	0·05	0·13	0·01
Manganese, parts per million	0·33	1·13	—
Phosphorus, per cent.	0·22	0·59	0·10
Potassium, per cent.	0·14	0·11	0·16
Sodium, per cent.	0·13	0·07	0·16
Sulphur, per cent.	0·183	0·157	0·196

Mineral content of the white.—The amount of mineral material in the white is relatively small, sulphur being present in greatest amount, with sodium, potassium, and chlorine next in order. The percentages of calcium, magnesium, and phosphorus are low, while copper and iron occur only in traces.

Mineral content of the yolk.—The ash content of the yolk, which is almost double that of the white, is qualitatively complete in its constituent minerals, for it contains all the elements necessary to the formation of the blood, bone and soft tissues of the animal body. Phosphorus, which accounts for a considerable proportion of the total mineral content, occurs chiefly in organic combination as phosphoproteins and lecithins. Sulphur, which is less abundant in the yolk than in the white, is present entirely in organic form, about half of it, as already mentioned, being contributed by levitin. The calcium content, though approximately ten times that of the white, is nevertheless low, but the embryonic chick makes good this deficiency by drawing on the shell for the bulk of its calcium requirements.

The iron of the egg is confined almost solely to the yolk, where it is believed to be present in inorganic form, though very closely associated with the protein. The yolk, compared with other foods, is relatively rich in iron compounds which, moreover, appear to be in an easily assimilated and utilized form, as they constitute the only source of iron available for the formation of the blood and tissues of the chick. Individual eggs show marked differences in iron content ; values ranging from 7·7 to 17·3 mg. per 100 g. of dried yolk have been observed in eggs from birds receiving very similar rations.

The iodine and copper contents vary considerably from egg to egg, but the amount present is always so low (as it also is in other foods) that it is reckoned in millionths of a gram. The copper appears to be concentrated largely in the yolk, but little is known as to the distribution of iodine between yolk and white ; figures available refer usually to the iodine content of the whole egg. The iodine content as shown in Table I is rather lower than the average, which is probably accounted for by the fact that the estimations were made on eggs produced in the United States, where, in many areas, particularly in the middle West, the soils and water are deficient in iodine, and this deficiency is reflected in the iodine content of the foodstuffs from these areas. Estimations by other workers indicate that eggs from hens on ordinary rations may contain amounts ranging from 3 to 80 μg. (1 μg. = 1 millionth of a gram).

Vitamin Content of White and Yolk

Vitamin content of the white.—The white is not a source of vitamins other than one member of the vitamin B complex. It contains neither vitamin A nor vitamin D, because these are both fat-soluble and the white contains practically no fat. There is no vitamin C in either white or yolk, a dietary source of this factor being apparently not required for the well-being of the chick.

Vitamin B complex.—It is now recognized that what was formerly known as vitamin B is really a mixture of several vitamins, of which only two, viz. vitamin B_1 and riboflavin need be mentioned here. The white of the egg is noteworthy in that it contains little or no B_1 but has a relatively high content of riboflavin. There are about 200 to 500 μg. per 100 g. of white, which is considerably more than is found in many other foods, so that egg white is a valuable source of this factor.

Vitamin Content of the Yolk. Vitamin A.—The vitamin A content of the yolk is high but variable (normal values are 200 to 800 International Units per egg), being influenced by dietary and physiological factors. The nature of the hen's ration, as we shall see later, has a marked effect on vitamin potency, but the amounts of vitamin A and vitamin A-producing substances deposited in the egg differ widely in different hens, even when they are on the same ration.

The vitamin A activity of the egg is due to the combined actions of vitamin A itself, carotene (which is transformed into vitamin A in the animal body) and kryptoxanthin. Xanthophyll, which accounts for most of the colouring matter of the yolk, is not a source of the vitamin.

Vitamin D.—Among the foods which are naturally rich sources of this vitamin, certain fish oils, e.g., cod-liver and halibut-liver oils, head the list, but egg yolk, though far less rich, is probably the second best natural food source. One egg yolk may contain from 10 to 50 International Units of vitamin D, the amount present depending upon the dietary regime and environmental conditions under which the eggs are produced.

Vitamin B complex. Vitamin B_1.—In the egg this vitamin is confined to the yolk. Comparatively few estimations have been made of its content, but it probably contains from 20 to 40 International Units.

Riboflavin.—The yolk contains a rather larger amount of this factor per unit weight than the white, the content ranging from 600 to 1200 μg. per 100 g. According to Wang and Kodicek (private communication) an entire egg will contain 140 to 300 μg. and it is therefore richer in this vitamin than most other foodstuffs, with the exception of certain animal tissues such as liver, kidney and the glandular organs.

Nicotinic acid.—The same authors (private communication) report that an egg contains 40 to 50 μg. of nicotinic acid, almost all in the yolk. It is not known to what extent dietary and other factors determine the nicotinic acid content.

EFFECT OF DIET ON COMPOSITION

Since the egg is an important article of our diet and one of the most valuable of the "protective" foods, it is a matter of considerable interest to the consumer to ascertain in what ways and to what extent the ration and management of the hen may affect its composition and nutritive properties. Recent research has shown that the egg is by no means a standard product and that variations in its chemical composition, vitamin content, and hatchability may be brought about by appropriate diets.

The poultry farmer endeavours to secure the highest possible production of eggs, of a quality which will contain the maximum amounts of essential elements and compounds needed for the development of a strong and healthy chick, while the dietician wishes to obtain eggs which will have a high value from the point of view of human nutritional requirements. Fortunately, the system of rationing and management which will best fulfil the farmer's purpose, results also in the provision of a human foodstuff of optimum quality.

Egg size.—Egg size is fundamentally an inherited characteristic, but minor variations may be brought about by the diet of the hen. Inadequate amounts of food or food containing too low a level of protein will reduce the size of the eggs, while the feeding of milk will have the reverse effect.

Flavour.—The taste and odour of the egg, and of the yolk in particular, may be adversely affected by certain feeding stuffs such as onion tops, rape, or turnips. Fishmeal also, if of inferior quality or if fed in too large amounts, will impart an unpleasant flavour to the yolk.

Yolk colour.—Though there is evidence that the capacity of transmitting pigment to the yolk is inherited, the colour is influenced primarily by the nature of the food consumed. Hens kept in confinement and fed on cereals such as oats, wheat, and their by-products, will lays eggs with pale-coloured yolks, but the colour rapidly deepens when the hens are allowed access to grass, or are fed on yellow maize, dried alfalfa, or other xanthophyll-containing foods. While the colour of the yolk is a rough measure of vitamin A potency, in the sense that green foods which increase the colour will also produce yolks rich in the vitamin, yet a pale yolk is not necessarily an indication of a low vitamin A value. Hens fed on a ration devoid of yellow maize and green stuff, but receiving a cod-liver oil supplement, will lay very pale yolks which contain adequate amounts of vitamin A.

Fat.—One of the constituents of the egg that is markedly affected by the diet is the fat. The actual amount present can probably be influenced only to a minor extent, but the chemical composition may vary greatly according to the type of fat present in the ration.[7]

Normally the fatty acids of the yolk are manufactured from the carbohydrate in the food. When, however, certain unsaturated oils such as hemp oil or linseed oil are fed at high levels, it has been found that their fatty acids are deposited by the hen in the egg fat. The result of this is to alter greatly the proportions of the fatty acids usually present. Oleic acid, which in the normal egg is the fatty acid present in greatest amount, is much reduced and the linolic acid is increased. The linolenic acid (the acid characteristic of linseed oil) may be increased to over five times the normal by feeding linseed oil in the ration. Such changes in fat composition do not occur under ordinary conditions of feeding, because linseed and hempseed are seldom included in poultry rations. Therefore they are of academic rather than dietetic interest, but they serve to illustrate the statement that the egg is not a standard product.

Fat-soluble vitamins.—The *vitamin A* content of the food will modify appreciably the vitamin A content of the egg. If the ration is low in vitamin A, the eggs produced will contain only a small amount of the vitamin, but the addition of 2 per cent. cod-liver oil to such a ration will result in a fivefold increase in potency in the eggs. Allowing the hens access to pasture has a similar effect. The use of yellow maize and dried alfalfa, both common constituents of poultry rations, also results in the production of eggs rich in vitamin A.

By feeding large amounts of cod-liver oil or administering a vitamin A concentrate, it is possible to increase the potency considerably above the normal, but there appears to be a limit to the amount of the vitamin that the hen will transfer to the egg, and the proportion transferred decreases rapidly as the intake increases.[8]

Vitamin D.—The vitamin D content of the egg is dependent on the sources of vitamin D available to the hens. When the birds are kept in confinement, vitamin D is usually supplied in the form of cod-liver oil. When they are on free range, they are independent of dietary supplies of the vitamin, since their requirements are met by the action of the ultra-violet rays of the sun on the body. Bethke and his associates[9] have shown that hens having access to grass pasture (and therefore exposure to sunlight) will produce eggs ten times as rich in the vitamin as eggs from hens on the same ration but confined indoors. Artificial irradiation of the hens with ultra-violet light will produce a similar increase in vitamin D potency ; 2 per cent. cod-liver oil in the diet will induce storage of five times more vitamin D than a basal diet alone. It appears, therefore, that cod-liver oil may be less effective in this respect than sunlight or artificial irradiation.

We have seen that there is only a limited transfer of vitamin A from the food to the egg, but vitamin D does not appear to be restricted in this way. By the feeding of vitamin D concentrates, extraordinarily high potencies may be produced in the yolk. The highest values are reported by Branion,[10] who succeeded in increasing the potency of the yolk to 600 times the normal by feeding large doses of irradiated ergosterol. These highly vitaminized eggs contained about 48,000 I.U. of vitamin D per yolk; they were, indeed, vitamin concentrates themselves. It is evident, therefore, that the vitamin D content of the egg may be influenced to a much greater extent than the vitamin A content.

While such immense variations in vitamin D potency can be produced only under experimental conditions, there is no doubt that the antirachitic value of market eggs differs appreciably in accordance with the methods of feeding and management employed by the producers. Under wartime conditions economic and other considerations will foster the "extensive" system of poultry husbandry (i.e., housing the birds so that they have freedom to range over grass land) with a probable beneficial effect on the vitamin D content of home-produced eggs.

Vitamin B complex.—Ellis *et al.*[11] found that the *vitamin B_1* content of the egg was influenced by the diet of the fowl. He showed that a supplement rich in B_1, such as rice bran, when added to a diet low in this factor, would considerably increase the vitamin B_1 content of the egg. The rations normally fed to poultry, which consist mainly of cereals and their by-products, are well supplied with B_1, so that the average egg is not likely to be low in this vitamin.

Riboflavin.—The amount of riboflavin in the egg appears to be directly related to the riboflavin content of the food. When supplements such as casein or meat meal form the sole source of protein in the ration, the riboflavin content of the eggs will be low, about 6 μg. per g. of air-dried egg. When protein is supplied in the form of dried skim milk and alfalfa, both excellent sources of riboflavin, the content of the egg may be raised to 20 μg. per g.[12] Since deficient eggs show high embryonic mortality and consequently very poor hatchability, it is important from the poultry farmer's point of view to have a high content of this factor present. His efforts to secure this will be of value also to the consumer of eggs.

Mineral content.—Comparatively little attention has been paid to the effect of diet on the mineral constituents of the egg.

Calcium.—There is no experimental evidence to show that the calcium content of yolk or white may be modified, but when the calcium in the diet is below the optimum, especially with high-producing hens, a thinning of the egg shell will result. This also occurs when vitamin D is deficient, since in this case the bird cannot utilize efficiently the calcium present in the ration. This point is of great importance in the marketing of eggs, because of the difficulties which occur in transport and storage when the shells are thin and fragile.

Iron and copper.—Various attempts have been made to increase the iron and copper content of the egg by increasing the hen's intake of these elements. Early workers maintained that this could be achieved, but recent evidence, which is in all probability more reliable because of the greater accuracy of the analytical methods now employed, does not support this view. McFarlane,[13] working with rations which differed considerably in iron content, could find no definite trend attributable to the diet. The Wisconsin workers[14] demonstrated that the feeding of iron or of iron plus copper in the form of inorganic salts had no influence on the mineral composition of the egg. Both these constituents vary considerably in individual eggs, but the amount present appears to depend on factors other than the amount ingested in the food.

Iodine.—In contrast to the findings with iron and copper, the iodine of the egg is greatly influenced by the iodine intake of the bird. The normal content can be increased many times over if iodine as potassium iodide is administered in the drinking water, or if rations containing either organic or inorganic iodine are fed, both these forms apparently being equally available for transfer to the egg.[15]

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CHAPTER III

THE NUTRITIVE VALUE OF THE EGG

By S. K. Kon

Eggs share with milk the ability to satisfy the nutritive requirements of warm-blooded organisms during a period of rapid development. They contain, therefore, a variety of essential food materials, "good" protein, minerals, and vitamins; they have, in fact, all the attributes of a "protective" food.

TABLE I

Composition of diets

	Bacharach and Drummond		Widdowson*
	Optimal	Marginal	
Total Calories	3500	3000	3000
Protein total	100 g.	50 g.	100 g.
animal	50 g.	30 g.	65 g.
Fat	120 g.	50 g.	130 g.
Carbohydrate	485 g.	570 g.	350 g.
Calcium	1·5 g.	0·75 g.	0·87 g.
Phosphorus	1·5 g.	1·0 g.	1·6 g.
Iron total	20 mg.	10 mg.	17 mg.
available			11 mg.
Vitamin A (and carotene)	7000 I.U.	3000 I.U.	—
Vitamin B_1 (aneurine)	1000 I.U.	350 I.U.	200–450 I.U.†
Riboflavin	2 mg.	?	—
Vitamin C	75 mg.	25 mg.	—
Vitamin D	400 I.U.	200 I.U.	—

* Rounded off mean figures for men of all age-groups.
† McCance, *et al.*,[3] values for pregnant women.

The chemical composition of the hen's egg, its important minerals, and the limits within which the several vitamins it contains vary according to the season and the nutrition of the hen have been discussed in the last chapter. We can therefore make use of the figures quoted by Dr. Cruickshank[1] in assessing the importance of the egg in the human dietary. To do this we must also have a measure of the requirements of the human being for the various components of his daily ration. These vary enormously according to individuality, age, sex, occupation and climate, and many assessments of "average" needs of the different nutritional classes have been made. I intend to use here as a basis the estimates put forward by Bacharach and Drummond[2] five years ago and to calculate the contribution of the egg to both their optimal and marginal diets. The components of these diets, as far as they have been used in my calculations, are given in Table I, where they are also compared with the results of the English dietary surveys of McCance and Widdowson.[3]

It is of interest to note the good agreement on major constituents between the optimal diet of Bacharach and Drummond and the survey estimate of Widdowson obtained on 63 healthy men of the English middle class whose dietaries could be considered to be "freely chosen" as far as money was concerned. The only striking differences are in the consumption of calcium. It is possible that the "optimal" estimate is too generous in this respect. On the other hand it seems probable that Bacharach and Drummond's estimate of riboflavin requirements represents rather marginal than optimal values.[4] For this reason I have used their estimate in the calculation for the marginal but not for the optimal diet. In assessing the role of the egg in human nutrition I have compared it with three other typical "protective" foods, milk, cheese and liver. One egg has been taken as a basis of comparison. It is impossible under war conditions to draw any reliable comparisons of prices, but it may be taken that ½ pint of milk can be bought for the price of one egg. 2 oz. of ox liver will supply the same amount of calories as an average egg at a similar price and, finally, 1 oz. of Cheddar cheese may also be used in this comparison. The results are given in Figs. 1, 2 and 3. Each parallelogram expresses as percentage of the daily requirement the amounts of the various nutrients supplied by one egg or by the equivalent quantities of milk, cheese and liver.

For each food the first parallelogram represents the contribution to the optimal, the second to the marginal diet. In all figures the egg comes first and the parallelograms for cheese, liver and milk are shaded. The analytical data used in the calculations are summarized in Table II.

It will be seen that one egg supplies about 2 per cent. to 2½ per cent. of the daily requirement of calories of the average man. This is only a slight contribution, but in assessing the merits of "protective" foods their energy value need not unduly affect the judgment, as calories are more cheaply and easily obtained from other sources.

From 7 per cent. to 13 per cent. of the total protein requirements and 13 per cent. to 23 per cent. of the animal protein considered necessary for satisfactory or perfect nutrition can be derived from a single egg. This in itself is important, but the value of a protein cannot be simply reckoned as a matter of ounces. We now know that the various proteins differ markedly in their so-called biological value, that is, in the degree to which they can serve in building and repairing body protein. Animal proteins are, as a rule, superior in this respect to vegetable proteins, and the proteins of the egg are pre-eminent among them. Experiments on animals[5,6,7] have shown that the biological value of the proteins of whole egg has not been surpassed by that of any other food tested, and experiments with human beings[8,9] support these findings. It has been also shown[6] that the proteins of egg can blend themselves with and improve the proteins of white flour by supplying them with certain essential amino-acids, the building stones of proteins. This is an important property, shared also by the proteins of milk, as in a mixed diet it is the biological value of the proteins of the mixture that counts. Taken separately the proteins of egg white are not quite as valuable as those of whole egg and they are not as efficient in supplementing white flour proteins.[6] It is well known that the digestibility of egg white is improved by cooking.[10] Experiments on animals have shown, moreover, that egg white may be harmful when taken in large quantities, especially in the raw state,[11,12] though human beings seemed to tolerate it well for short periods.[10]

TABLE II

Constituent	Amount present in			
	One egg (*a*)	½ pt. milk (*b*) (3·5% fat)	2 oz. ox liver (*c*)	1 oz. Cheddar cheese (*d*)
Calories	74	205	73	120
Protein, g.	6·8	9·9	11·6	7·1
Carbohydrate, g.	—	14·0	0·96	Trace
Fat, g.	5·5	10·3	2·6	9·8
Calcium, mg.	30·0	375	6	230
Phosphorus, mg.	110·0	280	208	155
Iron, Total mg.	1·6	0·1	5·2	0·16
Iron, Available mg.	1·6		4·7	
Vitamin A (and carotene), I.U.	200–800 (*e*)	200–1000 (*e*)	14,000	200–1000 (*e*)
Vitamin B_1 I.U.	40	45	50	1?
Riboflavin, μg.	100–350 (*e*)	290–580 (*e*)	1,400	100–200? (*e*)
Vitamin C, mg.	—	6	22	—
Vitamin D, I.U.	10–50	2?	5?	2?

(*a*) Values taken from Cruickshank's[1] paper.

(*b*) Data from National Institute for Research in Dairying.

(*c*) Chemical composition from Rose, "A Laboratory Handbook for Dietetics," 1937, 4th Ed., New York: The Macmillan Co.; and from McCance and Widdowson, "Chemical Composition of Foods," 1940, London: H.M. Stationery Office. Vitamin contents mostly from Fixsen and Roscoe, *Nutr. Abstr.*, 1938, **7**, 811; also from Pyke, *J. Soc. Chem. Ind.*, 1939, **58**, 338, and from Mickelsen, Waisman and Elvehjem, *J. Nutrition*, 1939, **17**, 269; **18**, 517.

(*d*) Chemical data from McCance and Widdowson. Vitamins, N.I.R.D. experience and Pyke.

(*e*) Variations due to season and diet of cow or hen.

There are only traces of carbohydrate in the egg. This can be much more profitably obtained from bread. Some 5 per cent. to 10 per cent. of the daily fat ration is found in one egg, but to cover our requirements from this source would be an expensive matter.

Turning now to the minerals present in the egg, we find that it supplies only a small fraction of calcium and a larger proportion of phosphorus, but it is in its relatively high content of iron that the mineral importance of the egg lies. It will supply from 8 per cent. to 16 per cent. of the total requirements. Widdowson[3] has shown that a good English dietary supplying 17 mg. of iron daily contains only 11 mg. in assimilable form. On this basis the contribution of the egg, the iron of which is 100 per cent. available, reaches 12 per cent. to 25 per cent. It has been shown by many authorities that egg yolk is excellent as a source of iron for young children.[10]

The importance of vitamin A in human nutrition cannot be too strongly emphasized. Its lack not only undermines the resistance of the body to illness and infection, but the vitamin is essential to the proper functioning of the eyes and even a slight deficiency may seriously affect the ability to see in subdued light with disastrous consequences under black-out conditions. The amount of vitamin A supplied by an egg varies, as shown by Dr. Cruickshank,[1] according to the diet of the hen. It may yield over a quarter of the quantity postulated for the marginal diet. It should be noted that, unlike the pigment in milk and butter, the yellow pigment of egg yolk is of little value to the human being as a source of vitamin A; it consists mostly of the inactive xanthophyll. When hens are given cod-liver oil, quite pale yolks may contain large amounts of vitamin A. Under war conditions, when cod-liver oil may be scarce and there may be a reversion from battery to outdoor poultry farming with much greater access to grass, the yellowness of yolks will run roughly parallel with their vitamin A content.

Vitamin B_1 is concerned in the assimilation of carbohydrates and in the functioning of the nervous system, and vitamin B_1 deficiency is still one of the major health problems of certain Eastern communities where beriberi continues to claim victims. Though obvious cases of deficiency are very rare in this country, there is little doubt that many poorer people, and especially expectant and nursing mothers, do not take enough of the factor. The contribution of the egg is only of moderate significance, 4 per cent. to 11 per cent. of the marginal or optimal intake.

Riboflavin is another member of the vitamin B complex, and it is definitely known that it is essential in human nutrition. The egg is a good source of this factor, and one egg supplies up to nearly 20 per cent. of the required quantity.

There are only traces of vitamin C in the egg. When the diet is deficient in this factor for a sufficiently long time scurvy develops, affecting the teeth and joints. Though matters in this country very rarely reach such a severe stage, special tests show that the vitamin C intake of a number of children and adults is too low for well-being and that the diet of many nursing mothers does not allow them to secrete enough of it in their milk. Potatoes, fresh vegetables, and fruit are the main sources of this vitamin in an adequate diet.

Most dietaries of civilized people contain only very little vitamin D; a deficiency of vitamin D leads to rickets in the infant and child and is quite prevalent in most countries. As a matter of fact, it may be taken for granted that, unless special care is taken, nearly every child is bound to suffer from the disease to a greater or lesser extent. What the requirements of the grown-up are for this vitamin is not known with certainty, but the amounts quoted in Table I are probably quite satisfactory. The amounts needed to prevent or cure rickets in children are better known, but it appears at present that much more of the vitamin may be required to produce sound and healthy teeth than is needed to prevent visible signs of rickets. Vitamin D is contained only in very few natural foods, and in this respect the egg is quite an important source. The contribution varies from 2·5 per cent. to 25 per cent., according to the richness of the egg and the quality of the rest of the diet.

In addition to the vitamin factors just discussed, several others are known to exist, and one or two of them have been proved to be essential to the human being. Not enough, however, is known about their distribution in the egg to include them in this summary.

Turning now to a comparison of the dietary value of eggs with that of comparable quantities of the other protective foods, the contribution of one egg is contrasted in Fig. 1 with that of half a pint of milk. It will be seen that there is little difference in the calories, protein, fat, vitamin A, vitamin B_1 and riboflavin obtainable from both these sources. Milk is a much more important source of calcium than egg; in fact, together with cheese it is much the most important source of this essential element in the human dietary. It supplies also more phosphorus and more vitamin C than the egg. The egg, on the other hand, is rich in iron in which milk is so deficient; it also supplies a much larger quantity of vitamin D. It will be seen, therefore, that these two important protective foods supplement each other nutritionally, and hence a combination of milk and eggs can serve as the backbone of high quality diet. The same can be said regarding the comparison of egg and cheese (Fig. 2), only here some of the important constituents of milk have been lost in the whey or otherwise during the process of manufacture.

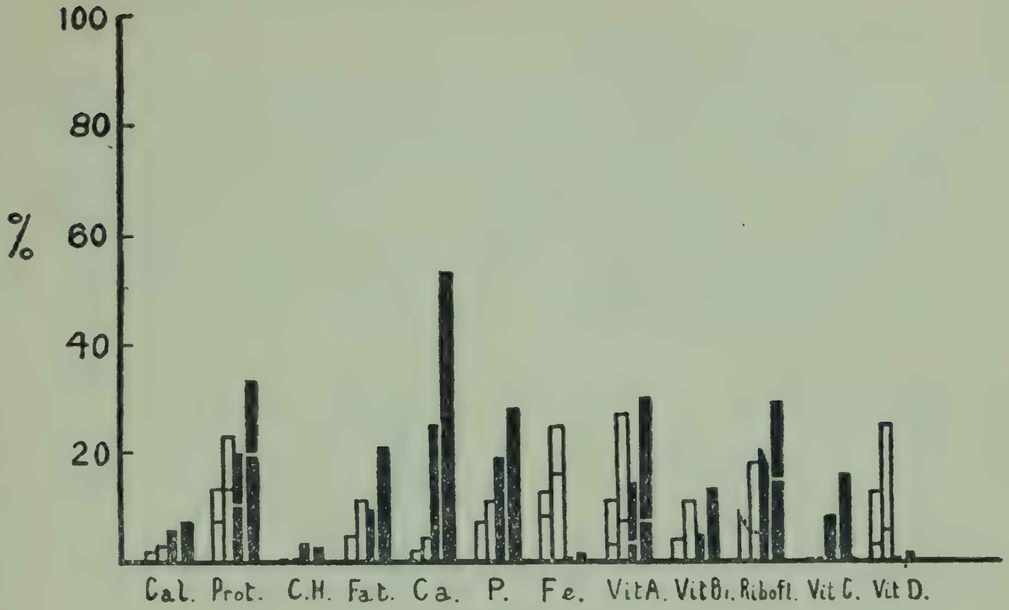

FIG. 1

FOOD CONSTITUENTS IN ONE EGG OR IN ½ PINT OF MILK EXPRESSED AS PERCENTAGES OF THE DAILY REQUIREMENT IN OPTIMAL AND MARGINAL DIETS

Remarks.—Unshaded parallelograms—egg; shaded—milk. In both cases the first parallelogram represents contribution to optimal, the second to marginal diets. Parallelograms divided by a horizontal line have the following meaning: Protein, lower part—contribution to total protein requirement; whole parallelogram—contribution to animal protein. Iron, lower part—contribution to total iron; whole parallelogram—to available iron. Vitamin A, riboflavin, vitamin D, lower part—the smallest, whole parallelogram the largest, contribution according to fluctuation in foodstuff. The broken riboflavin parallelograms indicate that optimum amount is not well defined.

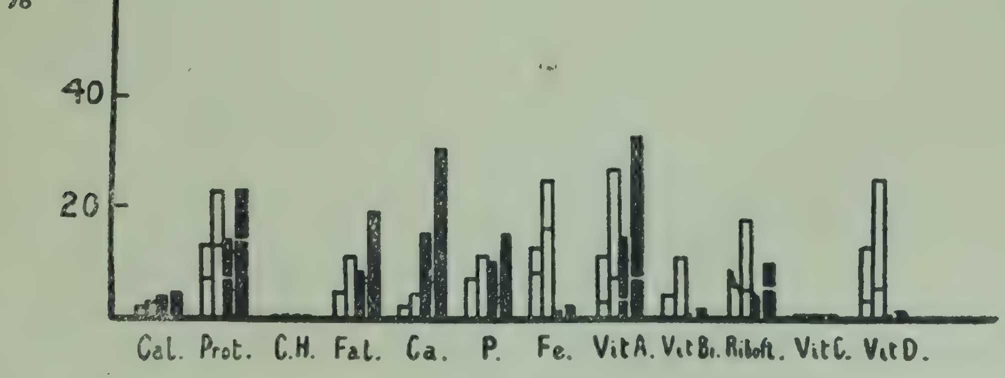

FIG. 2

FOOD CONSTITUENTS IN ONE EGG OR IN 1 OZ. OF CHEDDAR CHEESE EXPRESSED AS PERCENTAGES OF THE DAILY REQUIREMENT IN OPTIMAL AND MARGINAL DIETS

(*For remarks see Fig.* 1.)

Nevertheless, here again the contributions from both sources dovetail in a most satisfactory manner.

My third comparison is with ox liver, and a glance at Fig. 3 shows the richness of liver in most essential factors. It easily surpasses the egg in almost every respect with the exception of vitamin D. Though it appears so impressive, in practice the liver is not likely to challenge the importance and significance of eggs and milk as protective foods *par excellence*. The reason is simple; it takes one ox to produce one liver and the supply cannot be increased without increasing at the same time out of all proportion the supply of meat. These few comparisons are by no means complete. The egg should also be compared with such foodstuffs as fish and meat. These will, however, be considered at length in later chapters and their relative merits there brought out in detail.

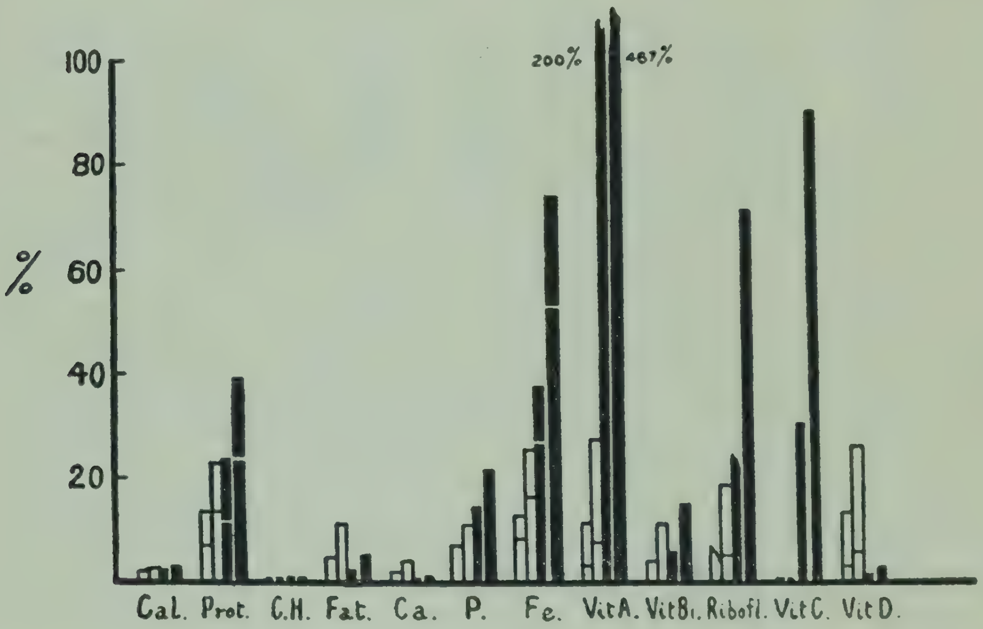

FIG. 3

FOOD CONSTITUENTS IN ONE EGG OR IN 2 OZ. OF OX LIVER EXPRESSED AS PERCENTAGES OF THE DAILY REQUIREMENT IN OPTIMAL AND MARGINAL DIETS

(*For remarks see Fig.* 1.)

Like milk, the egg is probably of greatest importance in the diet of the young, children and adolescents, and also for the expectant and nursing mother. In this respect the study of Rose and Borgeson[13] is of interest. They showed that children receiving a good though simple diet in which one-third of the calories was obtained from milk, derived benefit from the addition of one egg daily. They were healthier than control children who were given no egg and the main difference was the higher haemoglobin values due to the additional iron derived from the egg. Many paediatricians recommend egg yolk as a safe source of iron and vitamin D in early infancy.

The figures quoted by Dr. Cruickshank and information brought forward in the present paper show that most of the essential factors of eggs are concentrated in the yolk. When it is considered that many children, and for that matter some adults, show sensitivity to egg white, the aptness of the following remark of a famous American expert on nutrition, Prof. H. C. Sherman, will be noted.

"The yolk is very much richer than the white in the calcium, phosphorus, and iron compounds which . . . are especially significant in human nutrition. It is often advantageous to use egg yolks without the whites in the feeding of infants and younger children. If it be desired to emphasize this point at the cost of a slight exaggeration, it may be said that, roughly speaking, the yolk is transformed into the blood, brain, bone, and muscle of the chick; the white into the chick's feathers—and a child doesn't have to grow feathers!"[14]

Having considered what we can obtain from an egg and compared it with other important protective foods, we may well ask ourselves now what position should eggs occupy in a well-balanced diet.

The components of the egg, especially of the yolk, are easily digestible; the fat for example is, as in milk, in a state of fine dispersion and therefore is assimilated with ease. In addition, the high iron content of eggs and their relative richness in the antirachitic vitamin D makes them an excellent supplement to milk in the diet of the infant at weaning and for the child. For similar reasons it is a valuable food for convalescents, in anaemia, and for tuberculous people.

But the egg has also its place, and an important one, in the diet of the normal healthy adult. In building the edifice of health, together with other protective foods, it lends strength and cohesion to the foundation and walls of energy-bearing foods. For this purpose eggs must supplement and not replace milk and they should not be introduced into the diet at the cost of diminishing the consumption of fresh fruit or green vegetables. There is little doubt, however, that a part of the money spent on meat could with benefit be used for the purchase of eggs.

Finally, there is another aspect which must not be neglected and that is the psychological effect on digestion and nutrition of savoury and well-prepared food. The significance of the egg in this respect is well known to every housewife, but the discussion of this subject I can well leave in better hands than mine.

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CHAPTER IV

THE PRESERVATION OF EGGS

By R. B. HAINES*

Since this article was first written, the war has caused great changes in the methods of transport of foods, so that the import of shell eggs, which prior to the war totalled some quarter of a million of tons annually, corresponding to roughly 22 million cubic feet of cargo space, much of it refrigerated, has been almost entirely superseded by the import of spray dried egg. Nevertheless, the cold storage of eggs in shell, with or without gas storage, remains the best commercial method for large-scale storage and transport of eggs when it is desired to store eggs in a condition as closely resembling the fresh article as possible. Spray dried egg will probably continue to be used where its special qualities of compactness and ease of transport are desirable. A brief note on the fundamental points involved in the preparation of this commodity is appended.

A summary of some of the chief types of change that are liable to occur when eggs are stored is given in Table I. By storage is understood cold storage, that is, storage at a temperature not far above 0° C.† with or without the addition of carbon dioxide or other substances to inhibit microbial growth. By such storage, eggs can be kept on a commercial scale in a condition very closely resembling the fresh article for periods up to about 9 months. Some other methods of storage are mentioned subsequently.

It will be appreciated that the summary in Table I is arbitrary, and certain types of change listed for convenience under one heading in reality lie in part under several or all of them. The important point to be emphasized is that the egg is not a stable system ; it is, in fact, changing from the moment of laying. The ideal method of storage aims at retarding or arresting these changes by suitable means, as well as counteracting spoilage by external agencies, e.g., invasion by micro-organisms. It is of the greatest importance that such changes should be arrested quickly in eggs that are to be stored for long periods, for not only do they proceed at an increasing rate once under way, but they also facilitate attack by bacteria and moulds.

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* Died, 1942.

† The yolk of the hen's egg freezes at – 0·65° C., but eggs can be successfully supercooled, so that commercial stores are best run at 29°–32° F.

TABLE I

Type of change	Effect	Control
Physical changes—		
Loss of CO_2.	Change in pH of white. Change in structure of mucin gel. "Thick" white → "thin" white.	Gas storage. Sealing pores of shell.
Loss of water.	Increased "air-space."	High humidity. Sealing pores of shell.
Transfer of water from white to yolk.	"Swollen" and "flabby" yolks.	Low temperature. Gas storage.
Mechanical removal of mucin coating of shell.	Increased evaporation? Increased bacterial invasion?	Correct handling.
Chemical changes—		
Changes in thick white.	"Watery whites." "Sunken" and "sided" yolks.	Low temperature and control of pH.
Changes in strength of vitelline membrane.	Weak yolks liable to rupture.	Low temperature and control of pH; gas storage.
Pigment changes.	Deep yellow colour in white.	High concentration of CO_2.
Microbiological changes—		
Fungal growth on shell.	"Whiskers." Mustiness.	Hygienic handling. Low humidity and low temperature. Gas-storage.
Fungal rotting.	Decomposition.	
Bacterial invasion.	Discoloration, odours, rotting. Green, black and red rots. Miscellaneous rots.	Hygienic handling. Sealing of pores of shell. Low temperature. No washing of shells. Adequate defrosting. Inhibitors of microbial growth?

CHANGES TAKING PLACE IN THE STORED EGG

(1) *Physical changes.*—Loss of carbon dioxide from the egg occurs fairly rapidly, resulting in a change of pH from about 7·6 in the white of eggs just laid, to about 9·4. The pH of the yolk remains fairly steady at about 6.[1] This change of pH in the white is important in two ways. First, it affects the growth of micro-organisms. Most bacteria grow best at a pH of about 7, most mould fungi at considerably below this. The early observations of Turro,[2] made long before these facts were known, that the white of really fresh eggs has a weaker germicidal action than that of older eggs, was thus quite correct as far as it went. There are, however, several other anti-bacterial systems in egg white besides the pH changes.[3] The second important effect of change of pH in the white is its action on the swelling of the mucin fibres, and hence in the quality of the thick white. The jelly-like condition of thick white is due to the framework of highly swollen mucin fibres, and the best pH for the maintenance of the mucin in the state corresponding most nearly to that in the fresh egg appears to be from 6·5–7·5.[1] It might perhaps be mentioned here that the proportion of thick white is primarily a

characteristic of the individual hen; in other words, the production of eggs with good quality whites should be sought by breeding.[16] The difference between hens are considerable (Fig. 1).

Loss of water by evaporation results in an enlargement of the air-space; since an enlarged air-space can readily be seen over the candling lamp, it has provided an easy means of detecting stored eggs and become accepted as one of the criteria of quality, not altogether logically perhaps, because a properly-stored egg may have a fairly large air-space and yet otherwise be quite good, having, in fact, only lost a little water. The point is important, however, because if eggs are cold stored in air, at any humidity higher than about 85 per cent., marked mould growth on the shells is likely to occur over protracted periods (about 5 weeks at 95 per cent. R.H. and 0° C. for example). At 85 per cent. relative humidity, however, considerable evaporation does occur and there is inevitably a fairly large air-space in an egg stored for, say, 9 months under those conditions. This difficulty can be overcome by the use of gas storage.

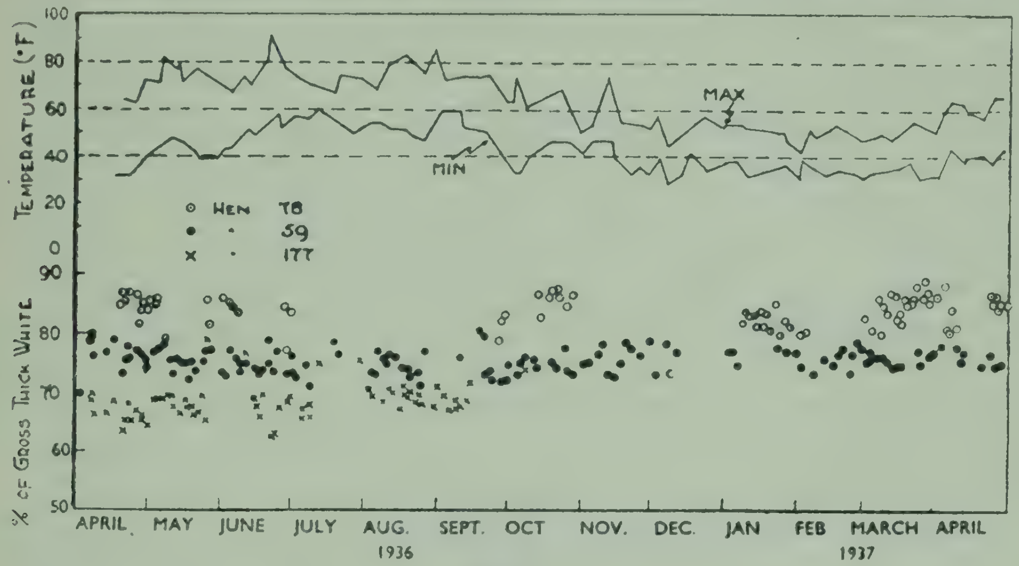

Fig. 1

PERCENTAGE OF THICK WHITE IN THE EGGS OF THREE HENS. (HALNAN AND MORAN.) NOTE (1) THE BIG VARIATION FROM HEN TO HEN; (2) THERE IS NO EVIDENCE OF ANY SEASONAL VARIATION FOR ANY GIVEN HEN OVER THIS PERIOD

The transfer of water from white to yolk is an osmotic phenomenon; the freezing point of the yolk of the newly-laid egg is lower than that of the white.[4] This movement of water leads to big changes in the viscosity of the yolk; a relatively small dilution with water lowers the viscosity considerably.[5] In common parlance the yolk is "flabby" or "runny" and the "yolk index" (ratio of height to diameter of yolk under defined conditions) is low, so that such eggs do not poach or fry satisfactorily. Such yolks are common in eggs that have been cold-stored for very long periods, and also in eggs that have been kept for a short time at "high" temperatures (e.g., air temperatures, a point not always appreciated by producers ; eggs that are to be stored in first-class condition must be cooled quickly). Storage in air containing quite small amounts of carbon dioxide (2·5 per cent.) tends to arrest this change, apparently by lowering the permeability of the vitelline membrane.[1]

(2) *Chemical changes.*—The changes occurring in the thick white are not yet fully understood. It is clear that the swelling of the glucoprotein, mucin, plays an important part, but, in addition to shrinkage or partial collapse of the gel framework, chemical changes also occur. The presence of a tryptic proteinase has been reported in the thick white,[6] but more recent work renders this unlikely, the ovo-mucoid fraction of the white, in fact, exerting an inhibitory action on tryptic digestion.[7] A possibility is that mucinases are present, or perhaps a purely chemical hydrolysis of the mucin molecule occurs. It is clear, however, that all changes of an enzymic or purely chemical character can be greatly retarded by rapidly reducing the temperature of the egg. A great deal of spoilage in industry in the form of "watery whites" occurs through failure to appreciate this point. Similar remarks apply to the changes taking place in the strength of the vitelline membrane. If the bursting strength of this membrane falls below about 2500 dynes per sq. cm. the yolk almost invariably breakes when the egg is opened[8]. In the new-laid egg an average value is 4500 dynes per sq. c.m.

Chemical changes in the white and yolk and perhaps in the shell itself undoubtedly influence greatly the egg's susceptibility to bacterial breakdown. Apart from the various anti-bacterial systems in the white, the native proteins are resistant to bacterial breakdown, and it seems possible that in the really fresh egg white the quantities of sugar and protein breakdown products are near the limiting concentrations that will support bacterial growth. Any enzymic breakdown therefore will materially assist growth should infection occur and apart from the chemical aspects of growth also assists microbial proliferation mechanically. The yolk is a very rich medium for the growth of micro-organisms, and changes making it more readily accessible appear greatly to accelerate rotting.

(3) *Microbiological changes.*—Although bacterial invasion of the developing ovum is known to occur, it is probable that the majority of eggs are completely or nearly sterile in the bacterial sense at the time of laying. The egg, in general, is however, laid into an environment

rich in micro-organisms, and one can by suitable means recover anything from 100,000 to 1,000,000 bacteria[9] and 200–500 mould spores[10] from an average "clean" egg shell. Among this population there is generally a fair proportion of potential rot-producing organisms; should they gain access to the interior of the egg, decomposition may set in fairly rapidly, even at low temperatures. Most members of the *Pseudomonas* group, for example, grow fairly well at 0° C. and an egg heavily infected with such organisms may become a "green rot" even at that temperature after about a month. The defences of the egg comprise a number of factors, including the coating of mucin on the outside of the shell, the shell itself, which is very variable in porosity, unfavourable *p*H in the white, and lysozyme and other anti-bacterial substances in the white. These are discussed in more detail elsewhere.[3] The yolk provides a particularly favourable medium for microbial multiplication and has, in fact, been used in the cultivation of some quite exacting organisms.

Microbial spoilage may take one of several more or less well-defined forms, but there are a large number of miscellaneous and mixed infections difficult to label. The better known or more easily docketed forms are:

Fungal spoilage	(1) "Whiskers" on the shell—superficial fungal spoilage. (2) Internal fungal rotting.
Bacterial spoilage	(3) Green rots of the *Pseudomonas* type. (4) Black rots of the *Proteus* or *Pseudomonas* types. (5) Red rots.

Whiskers on the shell consist of a more or less luxuriant felt of mycelium and hyphae, which may or may not have penetrated the egg. Even if they have not, the affected egg may have acquired a "musty" odour and flavour. Eggs are very susceptible in this respect; they readily absorb foreign odours. For example, stored in glass jars in which there have been cultures of *Actinomyces*, they acquire the characteristic "earthy" odour and taste which persist even after cooking.[12] If penetration of the shell occurs, the fungus multiples, often with a characteristic partial coagulation of the white, showing a dark spot over the candling lamp. *Sporotrichum* in the white gives rise to a pink rot, *Cladosporium* to black spots; once the yolk is reached, rapid and general decomposition sets in. Presumably for this reason eggs with "sided yolks" seem to rot rapidly, it being assumed that more or less direct penetration from the outside of the shell into the yolk takes place.

The bacterial rots perhaps need not be discussed in great detail here. They are all decidedly unpleasant except the *Pseudomonas* green rot, which in its early stages is rather pretty, at any rate to look at. *Pseudomonas* bacteria multiply in the white and and form their characteristic green fluorescent pigment.[9] Subsequently an unpleasant "cabbage-water" smell is produced. This type of green rot is by far the most common bacterial rot found in commerce, and it is difficult to check because in the early stages little change in the egg-white has occurred except the production of the pigment, and this cannot be detected over the candling lamp. Organisms of the *Pseudomonas* group occur commonly on egg shells, and in water and soil, and it seems probable either that direct washing or else wetting of shells infected with these bacteria has a great deal to do with the outbreaks of green rotting met with in industry. This point is discussed subsequently. Black rots of the *Proteus* type are very offensive, usually opaque over the candling lamp, and emitting a faecal odour. Sometimes much gas accumulates in the egg and the shell membranes appear to become impermeable so that the egg "bursts" on cracking the shell. Such eggs have acquired a descriptive but not very polite epithet in the trade.

It is true that a highly heterogeneous bacterial flora can often be isolated from such rots, but if fresh eggs are inoculated with pure cultures the main characteristics of the rot can be produced specifically by one organism, and this taken in conjunction with other evidence justifies the characterization of the rotting.[13,9] Certain bacterial infections appear to do little more than produce some turbidity in the white, sometimes with characteristic and unpleasant odours, e.g., the "mustiness" caused by some strains of *Achromobacter*[14] or the "fishiness" set up by some atypical coliform organisms that are often found in infected eggs.[9]

Apart from spoilage, the possibility of the infection of eggs with organisms pathogenic to man has to be considered. Cases of food-poisoning by members of the *Salmonella* group from duck eggs have been reported[39] and it is known that hens may be infected with various members of this group.[35,36] There appear to be no recorded instances definitely attributable to hens' eggs, and at worst but few sporadic cases are to be expected from occasional infection of single eggs, since, even if the *Salmonella* survived cold-storage and the subsequent treatment the egg received before consumption, relatively few people could be infected. But in any commercial process in which broken eggs are mixed in bulk, the question becomes of greater significance, and careful control is needed. Unrestricted bacterial development must not be allowed to occur in the pulp, since, in addition to the possible occurrence of *Salmonella*, enterotoxin producing organisms such as *S. aureus* may be present and

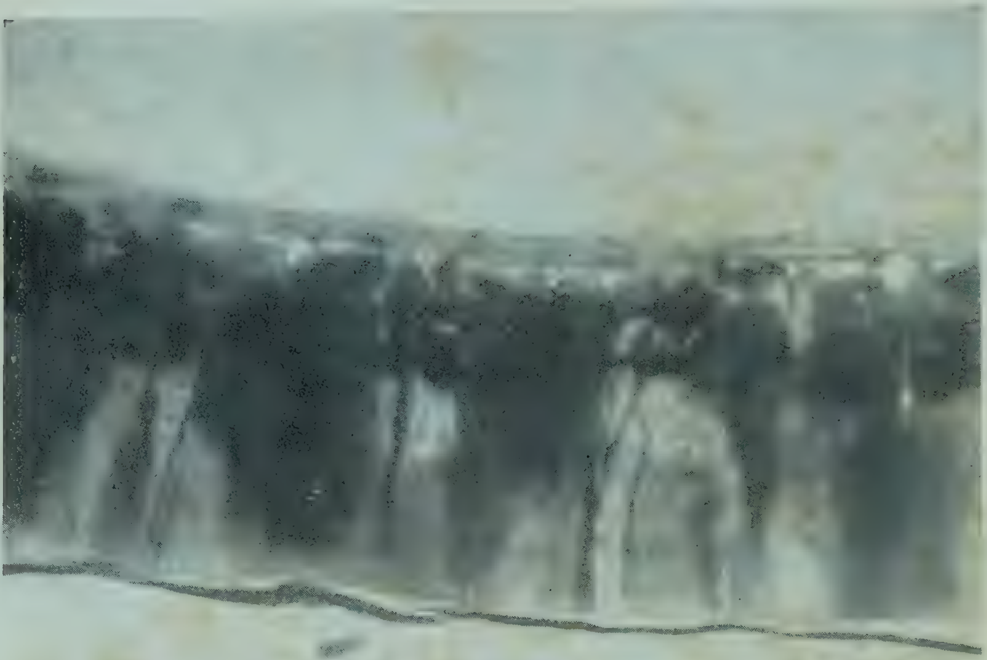

Fig. 2

TRANSVERSE SECTION, NORMAL TO SURFACE, OF EGG-SHELL (× 100), SHOWING PORES REACHING TO MAMMILLARY LAYER. (HAINES AND MORAN)

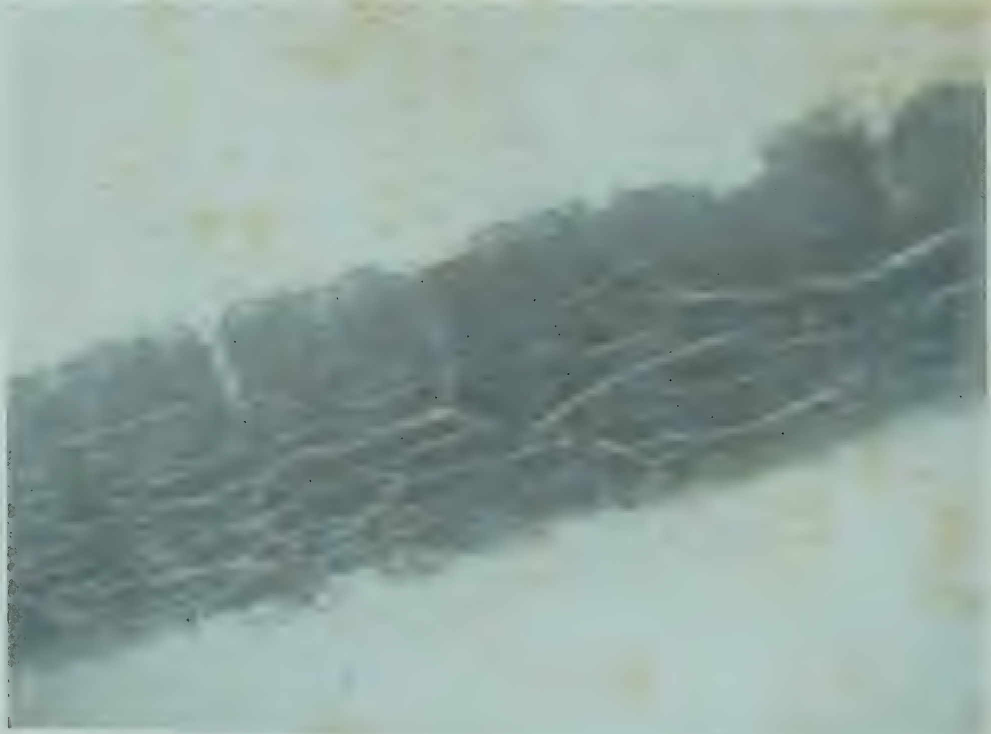

Fig. 3

TRANSVERSE SECTION, NORMAL TO SURFACE, OF EGG-SHELL (× 120), SHOWING FOUR LAYERS: (1) CUTICLE TOP; (2) SPONGY LAYER; (3) MAMILLARY LAYER BEGINNING ABOUT $\frac{2}{3}$ OF THICKNESS DOWN; (4) INNER SHELL MEMBRANE. (HAINES AND MORAN) produce toxic substances which will not necessarily be destroyed by such subsequent heating as the product may receive (see also below).

CONTROL OF MICROBIAL INFECTION

Little can at present be done in the control of what may be called the internal defences of the egg, except control of *p*H in the white by gas storage, but a great deal can be done to minimize bacterial infection and to ensure that only first-class produce is stored. The proportion of eggs spoiled by microbial rotting in commercial handling is often of the order of 5 per cent.[3] Taking the Ministry of Agriculture statistics for 1935,[11] the estimated egg production in England and Wales was 3024 millions, while 2373 million eggs in shell were imported. Considering the figure for imported eggs only, a loss of 5 per cent. thus means the rejection of some 150 million eggs. What can be done to reduce this waste? A few points can be stated categorically in the light of the facts presented previously; for some of the other points, which are more controversial, evidence will be given.

(1) The egg should be laid into as clean surroundings as possible.

(2) The egg should never be washed or the shell moistened with water at any stage.

(3) Eggs should be gathered as soon after laying as possible, candled to remove "physiological" faults, and cooled quickly to the temperature of storage.

(4) Eggs should be artificially defrosted on coming out of cold store, re-candled, and disposed of as rapidly as possible.

It is, no doubt, difficult always to put these principles into practice in industry, but the fact remains that the more closely they are approximated to, the less will be losses from spoilage. Point two, the question of washing, is one about which there has been a good deal of controversy, and it is perhaps worth digressing a little to consider it in some detail.

The shell of the egg consists of four layers. These are (1) coating of mucin, (2) spongy layer, (3) mammillary layer, (4) inner shell membranes. (Figs. 2 and 3.) Pores or V-shaped openings can be seen opening to the exterior; contrary to some statements in the literature, these do not pass right through the shell, but appear to become lost in a network of finer channels in the mammillary layer.[15] Bacteria and even yeasts (about 10μ diameter) can be pulled through the shell under pressure, and the porosity of the shell is much increased by washing out the protein material in the pores. The porosity of the shell is clearly a factor of great importance in microbial invasion, but it is difficult to get data to which more than a qualitative meaning can be attached, since the porosity is subject to a high individual variation even in successive eggs from the same hen. Fig. 4 shows the type of variation found. The porosity was measured by pulling water through portions of the shell, suitably mounted, under defined conditions. A recent study of the porosity of the shell on somewhat similar lines is by Romanoff.[37]

THE FLOW OF WATER THROUGH THE EGG SHELL

(Time for flow of 25 ml.) Eggs from the same hen over a period of 9 days

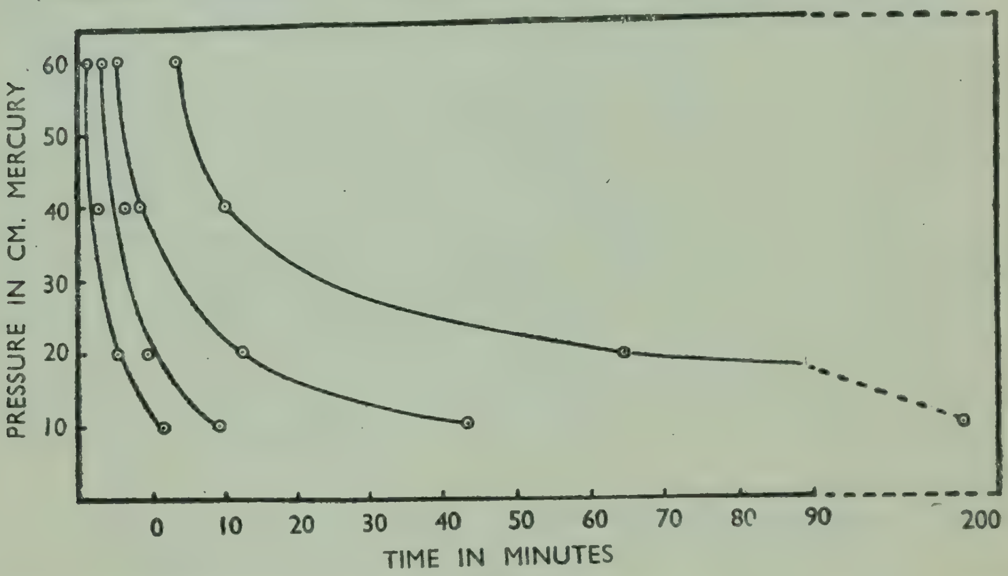

FIG. 4

POROSITY OF THE SHELL, AS MEASURED BY THE RATE OF FLOW OF WATER THROUGH THE SHELL AT VARIOUS PRESSURES. NOTE THE BIG DIFFERENCES IN POROSITY BETWEEN SHELLS OF EGGS FROM THE SAME HEN. (HAINES AND MORAN)

Now it is clear that when an egg cools from the body temperature of the hen to air temperature and air forming the "air-space" is drawn in, considerable suction is set up, and it might be anticipated that bacteria on the shell would tend to be drawn in, especially if the shell happened to be wet at the time. Experiments showed that this is so. (Table II.)

TABLE II

EFFECT OF THE RELATIVE TEMPERATURES OF THE EGG AND THE WETTING FLUID ON THE BACTERIAL ROTTING OF EGGS

Treatment	Number of eggs	Number of rots	Per cent. rots
Eggs cooled overnight after laying, soaked 1 hour in a bacterial suspension at approximately the same temperature as the eggs	119	16	13
Eggs cooled overnight at + 10° C., then soaked for 1 hour at + 25° C.	99	7	7
Eggs cooled overnight, brought to 37° C. in the incubator before soaking, then soaked for 1 hour in suspension at room temperature	50	50	100

Warm eggs immersed in a cool aqueous suspension of bacteria invariably developed a high proportion of rots on storage; cool eggs immersed in a warmer suspension of bacteria developed few or no rots. It seems likely that some of the conflicting statements in the literature on the subject of washing of eggs are due to neglect of this factor of the relative temperatures of egg and washing solution. In our view washing greatly increases the likelihood of rotting for three reasons:

(1) It is likely to lead to increased bacterial spread unless carefully controlled.

(2) It may partly remove the coating of mucin which helps to seal the pores.

(3) It leads to almost certain bacterial entry if warm eggs are immersed in a cooler washing fluid.

Methods of Storage

Innumerable methods for the storage of eggs have been propounded from time to time. The probable utility of any method can be examined in the light of the basic principles enunciated above. The use of water-glass, which is often quite successful on a domestic scale, may serve as an example. Fresh, clean, dry eggs of good quality immersed in water-glass can often be kept for 9–12 months. Water-glass seals the pores of the shell; it therefore prevents loss of carbon dioxide, loss of water and change in *p*H, thus maintaining the quality of the thick white and probably also preventing bacterial invasion. But eggs stored in water-glass can only be kept successfully if they can be put in a cool place; in other words, temperature control is required to retard deleterious chemical changes. It is sometimes said that eggs preserved in water-glass will not boil. Naturally, if an egg whose pores are completely sealed is heated it just bursts—the difficulty can easily be overcome by piercing the shell with a needle before cooking. The chief disadvantage of water-glass is its bulk. Certain other preparations now on the market for sealing the pores of eggs do not suffer from that defect.

On a commercial scale straightforward cold storage, or cold storage plus carbon dioxide, is the most generally useful method. An ordinary store, running at about 0° C. and 85 per cent. relative humidity, should keep eggs perfectly well for 6 months if fresh good quality material is put into it. Such eggs will, however, have a rather large air-space, and sometimes after about 5 months a certain proportion of the yolks will develop a slight but unpleasant metallic taste, the "storage taste." These difficulties can be largely overcome by the use of gas storage. Moran,[17] at the Low Temperature Research Station, critically compared three methods of storage on a fairly large scale. The results may be summarized as follows (Table III).

TABLE III

COMPARISON OF THREE METHODS OF STORAGE, 6–9 MONTHS

Cold storage	Partial gas storage	Full gas storage
0° C. and 85 per cent. R.H.	2–2½ per cent. CO_2, humidity controlled.	60–100 per cent. CO_2, no humidity control.
Shell smooth	Shell slightly rough	Shell slightly rough.
Air-cell large	Air-cell large	Air-cell small
White distinctly yellow	White faintly yellow	White faintly yellow.
Thick white weak	Thick white firm	Thick white firm but shrunken
Yolk flabby	Yolk firm	Yolk firm.
Storage taste	No storage taste	No storage taste.

The chief advantage of partial gas storage over ordinary cold storage is the prevention of "storage taste" and retention of a firmer yolk. Full gas storage also prevents "storage taste," and at the same time maintains a firm yolk and gives minimum loss in weight. The white, however, becomes watery. On the other hand, quality is very uniform; fungal growth is eliminated and there was not a single rot in 1800 eggs stored for 9 months by this method. Further details of these tests may be found in the original publications.[1,17]

It should perhaps be emphasized that eggs coming out of store must be marketed quickly—any micro-organisms present will not have been killed, at the best only retarded; they may even have multiplied to some extent (except perhaps in full gas storage) and the down-grade changes setting in during storage, even if only comparatively slight, will have lowered the egg's resistance to attack.

POSSIBLE NUTRITIONAL CHANGES IN THE EGG DURING STORAGE

Eggs are candled before and after storage, and an egg remaining in the first grade resembles the fresh article pretty closely. Neglecting vitamins for the moment, it seems *à priori* improbable that there is much change in food value during cold storage in terms of calories or content of particular amino-acids. The changes leading to loss of quality, e.g., movement of water from white to yolk or change in the gel structure of the mucin, are very slight in terms of what may be called orinary "chemical" decomposition. Any egg in which these changes had taken place, or in which there was obvious mould or bacterial growth, should be removed by the candler. Analytical data in the literature confirm this view that the chemical changes in cold-stored eggs are slight. Figures have been published for production of free ammonia in white and yolk,[18,19] decrease in lecithin content of yolk,[20] increase of acid-soluble phosphoric acid in the yolk,[21] increase in free fatty acid in the yolk[22] and so on. (A useful recent review of the literature is given by Grossfeld.[23]) In all instances the changes are comparatively small, e.g., Hendrickson and Swan[18] determined the "loosely bound nitrogen as ammonia" in white and yolk of fresh eggs and after 10 months' cold storage, their mean percentage figures being white 0·0004, yolk 0·0032, and white 0·0004, yolk 0·0061 before and after storage, respectively. That is to say, there was no detectable change in the white but a slight increase in ammonia nitrogen in the yolk. Whether this was due to the enzymes of the yolk itself or to bacterial activity was apparently not determined. In general, the chemical or enzymic changes taking place in the yolk are more pronounced than those occurring in the white. It seems probable that such changes as do occur are more important from the point of view of development of undesirable flavour than from the strictly nutritional standpoint. The foregoing remarks apply, of course, only to cold-stored eggs in shell. In frozen or dried eggs, different changes might be expected to occur.

It is not possible to make a categorical statement on the effect of storage on the vitamin content of eggs, since the findings reported in the literature do not all agree. Most of the work was carried out before the various vitamin complexes were resolved into their separate components, and for that reason each complex is referred to as a whole. If the egg becomes alkaline, there is a tendency for B to be lost, as is reported by Tso for pidan, but A and D were said to be little affected.[24] During cold storage, or even domestic preservation, the balance of evidence seems to suggest that there is no great loss in A and D over periods of 6 to 9 months,[25,26,27,28,29] although Manville[30] reported 75 per cent. losses after 12 months' cold storage, and 50 per cent. losses for eggs frozen or stored in waterglass for 18 months.

SPRAY DRIED EGG POWDER

In the production of spray dried egg the pulp obtained from mixing the yolk and white in the breaking room is fed to a jet or centrifugal spray drier, the essence of the process being that the atomized pulp meets a current of warm air, has its moisture content rapidly reduced to the level of about 5 per cent. or less, and falls as a fine powder to the floor of the chamber, from which it is removed continuously to avoid overheating. The heat treatment the individual particles receive cannot be accurately defined, but is of the order of seconds at about 60–70° C., from which it follows that much of the bacterial flora of the pulp will be unaffected. The bacteriological problems involved in the preparation of this product are thus very different from those of the handling of eggs in shell, where, as has been shown, each egg is an entity equipped with defences against microbial attack. Moreover, should an egg succumb to microbial invasion, it will often be eliminated by the candler; even in the unlikely event of its being infected with pathogenic organisms, at the worst it is capable of infecting relatively few people. On the other hand, a few infected eggs added to the pulp in a spray-drying plant could lead to the infection of a large batch, especially if opportunity were given for bacterial development before the pulp was dried. No bacterial multiplication can occur once the powder is dried, since the water content necessary for this is about 15 per cent., and about 10 per cent. for mould growth,[31] but organisms surviving the drying process may remain viable for long periods.

Two paramount considerations determine the limits within which the variables in the drying process must be controlled. These are, first, considerations of quality of the product, namely, flavour, ease of rehydration, cooking properties, nutritive value and the like, and secondly the bacterial content of the powder. The variables over which control can be exercised during drying are the temperature and rate of flow of the pulp to the drier, and the temperature and rate of flow of the air current.

Quality.—Assuming the use of eggs of reasonably good quality to begin with, the chief points to be noted are briefly as follows:

(1) The product must not be overheated during drying, or burnt flavours and low "solubility" may result.

(2) The moisture content must be reduced to 5 per cent. or below, the lower the better, otherwise chemical changes take place in the powder leading to "off" flavours and loss of "solubility."

(3) For prolonged storage some temperature control, gas-storage, or other means of retarding these chemical changes, chiefly of an oxidative nature, is desirable.

Nevertheless, if careful attention is given to the conditions of drying, so that the moisture content is reduced to a satisfactory level without impairment of the powder, and the product is packed in such a way that the subsequent uptake of water is minimized, powder of reasonably good quality can be transported without recourse to cold storage. For a discussion of these points, see papers by Bate-Smith, Brooks, Hawthorne and Bennion,[32,33,34] and Stuart, Hall and Dicks.[38]

Bacteriology.—The bacterial flora of spray dried egg powder is chiefly influenced by the following five factors:

(1) The bacterial content of the unopened eggs, which in turn depends on their freshness and quality.

(2) The bacterial flora of the shell, the care exercised to prevent its incorporation in the pulp, and the general hygiene of plant and personnel.

(3) The speed with which the pulp is dried, since rapid bacterial multiplication is to be expected if the pulp is left at temperatures suitable for bacterial growth. Changes in the bacterial population during freezing and thawing will occur when frozen pulp is used.

(4) The temperature of drying and the general efficiency of the drying process, e.g., freedom from drip at the nozzles.

(5) The interval between drying of the product and its consumption, since bacterial death may occur in the dry powder.

It is essential that adequate bacteriological control be exercised in the preparation of spray dried egg, for two reasons; first, because of the possibility of pathogenic organisms being present, and secondly because toxic substances may be formed that would not be destroyed in the spray drying.

Although in adequately controlled drying processes these points will be attended to, no dried egg is sterile, and therefore it is imperative that the product should be used within a reasonable period after rehydration, so that excessive bacterial multiplication does not occur in the reconstituted egg. The period of rehydration should in no circumstance exceed four hours.[31]

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CHAPTER V

THE EFFECT OF COOKING ON EGGS

By Mary Andross

This chapter devotes consideration to cooked eggs in various forms; the points we have attempted to study were (*a*) how to obtain the most attractive appearance, since we believe that the aesthetic side of presenting food has a definite bearing in nutrition, (*b*) digestibility *in vitro* after cooking in different ways, and (*c*) some effects on cost.

Eggs are used in cookery for various purposes. They are used for themselves; they are used along with other things to thicken custards and sauces, to aid emulsification and in mayonnaise, to hold air as in meringues, soufflés and sponges, and to bind and protect as in croquettes. Egg white is a hydrophilic colloid; this is important in poaching eggs and in increasing the volume of egg-white by adding water before beating. Egg protein would seem to be peptized by small quantities of salts. We found this in making omelets and in poaching eggs, but digestion experiments showed that the tenderness was only apparent. It must always be remembered that egg cooked in salted water is cooked at a higher temperature. Eggs are alkaline and the addition of acid by bringing the egg nearer the iso-electric point tends to alter the product. Coagulation temperatures are important in all forms of egg cookery. Many things affect coagulation temperature, whether egg is pure or mixed with other substances, the time temperature is maintained, *p*H, time taken to reach temperature and so on. Albumen is really denatured on cooking because of the electrolytes it contains, as shown by Lepesckin. High and low concentrations of electrolyte and acid give different results.

We have been sorely tempted by intricate problems regarding high-class egg cookery like soufflés and angel cakes, but having found no existing standards for simple egg cookery we have confined ourselves to simpler work on boiling, poaching, scrambling, frying, and making of omelets (simple). Those after all are the foundations round which the garnish of high-class cookery is built. As an example of eggs as thickening agents we have studied pouring and baked custards, and cooked mayonnaise. We have also studied meringues and sponge cakes.

EGGS IN SHELL

The following tests show the effect of temperature and time on egg boiling, and also show the time required to give the best results.

Boiling Eggs Hard

		Effect	
Temperature	Time	White	Yolk
72° C.	1½ hrs.	Curdy	Tough
85° C.	30 mins.	Tough set	Drier
100° C.	Starting hot, 12 mins.	Very tought set	Dry, soft centre
100° C.	Starting cold, 15 mins.	,, ,,	Dry

Prolonged heating at a low temperature does not set the white. Similarly it is not possible to obtain a dry yolk at this temperature. At 85° C. for 30 mins. the white is hard, but the yolk is no good for slicing. At 100° C. for 12 mins. starting in boiling water a soft spot is liable to be present in the yolk, making it unsatisfactory. The best result is obtained by putting the egg on in cold water and boiling for 15 mins.; the yolk then also separates easily from the white. If a hard-boiled egg is cooled in air, there is a black ring of iron sulphide round the yolk produced by H_2S from the white acting on iron salts of the yolk. This is reduced by cooling quickly in cold water. Lowe explains this as a reduced pressure at the surface, reducing the amount of H_2S in the neighbourhood of the yolk. This sudden reduction of heat also causes the egg to contract away from the shell, which can therefore be more easily peeled off. New laid eggs needed, if anything, longer boiling; this seemed to vary also with particular eggs.

Boiling Eggs Soft

The eggs were boiled for different periods to find the time giving the best result:

Time	White	Yolk
2 mins.	Very little coagulation	None
3 ,,	Slight coagulation	Slight coagulation at edges
5 ,,	Just coagulated	More at edge
7 ,,	Coagulated	Gelatinous
10 ,,	Coagulated and tough	Set

New laid required one min. longer to set curd.

Thus the best heating time is 5 mins. This averages for eggs of all ages. It was found on fitting an egg with a thermometer set inside it that, after boiling it for 10 mins., the inside temperature was no higher than 43° C. This explains the unset part so often found in the centre of the yolk after prolonged boiling. A boiled egg cut too soon may be sealed with salt, since a saturated solution of salt precipitates the globulin.

POACHED EGG

Eggs were poached in water with different quantities of salt, vinegar, and lemon juice. The eggs were judged by appearance, and area of spread. In poaching an egg there are four distinct layers, yolk, thick white, and a third which we have called the "frill." The last seems to consist of a thin layer and a mere wisp. This third layer increases with the age of egg. Addition of salt causes denaturing of the "frill" with the result that, though it sets better, it floats up and is apt to become detached. Addition of acid causes definite denaturing of third and fourth layers, and gives a puckered appearance to the surface of the egg.

If the curd be removed from a new-laid egg when this is half-cooked, it is immediately precipitated when dropped into a vinegar and water solution; vinegar gives coagulation as well as precipitation. Stirring water in pan before adding the egg causes the wisp to wind round and attach itself to the top of the egg when the latter is lifted out. Salt cooking in soft water like Glasgow water gives a different appearance from cooking in acid. The egg is shinier and more attractive, but the method is more wasteful, since there is a greater powdering off.

SPREAD ON POACHING

Poaching medium	Spread 40–60 sq. cm.	Spread 60–80 sq. cm.	Spread 80–130 sq. cm.
500 ml. Water	—	—	19 C.
Water— 5 ml. Vinegar	6 N.L.	—	—
,, 10 ml. Vinegar	—	—	15 P.
,, 5 ml. Lemon	5 N.L.	—	—
,, 10 ml. Lemon	1 N.L.	9 C.	—
,, ¼ teasp. salt	—	11 C.	—
,, ½ ,, ,, ...	—	12 C.	14 N.L.
,, ¾ ,, ,, ...	2 N.L.	10 P.	—
,, 1 ,, ,, ...	1 N.L.	—	—
,, ¾ ,, ,, ... + 6 ml. lemon.	3 N.L.	—	—
Water + ¼ teasp. salt + 5 ml. vinegar	—	13 C.	16 P.
Water + ¾ teasp. salt + 10 ml. lemon	—	8 C.	18 P.
Water + 1 teasp. salt + 10 ml. vinegar	4 N.L.	7 C.	—

The number of eggs used in each experiment is indicated by the figure next to the abbreviations, which have the following significance:
"N.L." = new laid; "C" = country; "P" = preserved as bought in shops.

New laid is obviously the best egg for poaching, preserved is the worst. This is not surprising, as the preserved eggs used had been preserved in water-glass for over a year. The lowest actual spreads are also for:

New laid
10 ml. lemon
¾ teasp. salt + 5 ml. lemon
¾ teasp. salt
¾ teasp. salt + 10 ml. lemon

Country
1 teasp. salt + 10 ml. vinegar
¾ teasp. salt + 10 ml. lemon

Preserved

10 ml. vinegar
¼ teasp. salt + 5 ml. vinegar (large waste)
1 teasp. salt + 10 ml. vinegar

From this we concluded that 10 ml. vinegar or 10 ml. lemon juice, or 10 ml. vinegar + ¾ teaspoonful salt in 500 ml. water is the best medium for poaching eggs. Lower salt and acid was not satisfactory; pure water gave poor result.

An interesting point was observed during poaching eggs. To begin with we thought that the only loss was in the egg which was flaked off. Then it was noticed that the water in which the egg was poached lathered on shaking. When this water was analysed for protein there was found to be from 3 per cent. to 8 per cent. It seemed to be highest in weakly acid solutions. On watching the egg carefully while it was poaching, there would seem to be a filmy layer of white extending between the thick albumen and the yolk covering which was not easily coagulable. Could this be a pseudo-globulin? Since there seems to be a corresponding loss of phosphorus this would seem to be a protein other than mucin. More work might be done on this. Boiling water violently in poaching eggs raises the amount powdered off considerably, i.e., by 10 per cent.

Scrambled Egg

Recipe: 100 ml. milk, 10 g. margarine, 100 g. egg.

There are many methods of what is called scrambling eggs, judging from the cookery books. We have found the most creamy egg is obtained by melting butter in a pan along with milk, and adding this when just boiling to the slightly beaten eggs. The egg and milk are then returned to the pan and heated slowly till set. This guarantees gradual heating of milk at the beginning.

Different amounts of milk were tested against two eggs to find how much the latter carry.

It can be seen from the following table that the greatest interval between coagulation and curdling, or the greatest margin of safety in cooking, is between 70° C. and 84° C., when 20 ml. of milk are added per egg. But 40 or even 50 ml. are possible if the cook is careful. It certainly ekes out the egg. Scrambled egg has a danger signal. When it is beginning to coagulate there is a fall in temperature. Evidently coagulation is an endothermic reaction. This is followed, on rise of temperature, by the shrinking of the curd and squeezing out of water. We have all experienced the crumbly and objectionable curd and the soppy toast of over-cooked scrambled eggs.

Amounts of milk carried by two eggs showing curdling and coagulation temperatures

Temp.	20 ml. milk	40 ml. milk	60 ml. milk	80 ml. milk	100 ml. milk	120 ml. milk	140 ml. milk	100 ml. milk + ¼ teasp. salt
40° C.	—	—	—	—	—	—	—	—
45° C.	—	—	—	—	—	—	—	—
50° C.	—	—	—	—	—	—	—	—
55° C.	—	—	—	—	—	—	—	—
60° C.	—	—	—	—	—	—	—	—
65° C.	—	—	—	—	—	—	—	—
70° C.	—	E.	—	—	—	—	—	E.
72° C.	—	—	E.	—	—	—	—	—
74° C.	E.	—	—	—	—	—	—	—
76° C.	—	—	—	E.	E.	—	—	—
78° C.	—	—	—	—	—	E.	—	C.
80° C.	—	—	C.	C.	C.	C.	C. and E. meet	—
82° C.	—	—	—	—	—	—	—	—
84° C.	C.	C.	—	—	—	—	—	—

"E." = coagulating temperature; "C." = curdling temperature.

Fried Egg

This is one of the most mutilated forms of egg. One French cookery book says fat must be "smoking hot"; our college cookery book says "just smoking," and Mrs. Beeton says "hot." But the cook can only fix two fat temperatures, the melting-point and the smoking temperature, both of which vary with the kind of fat. The chef does not exist who can tell the temperature of fat accurately by looking at it. Some experts were tried on this point, but they had to admit grudgingly that the first egg must be sacrificed. It is, indeed, a burnt offering at 235° C., "smoking hot." It is denatured violently. The white rises in immense bubbles and sparks of white fly. A brown indigestible substance results round the egg. The cook complains that her fat becomes dirty very soon owing to particles of protein breaking off. In deep frying we coat fish, etc., with batters to protect the protein, but no such protection is offered to the unfortunate egg.

The following table gives the ideal frying temperature.

Temperatures and times for frying eggs

Temperature	Time Min.	Appearance
115° C.	5	Too much spread
126° C.	4	Very good
137° C.	3	Excellent, very slight denat.
146° C.	2	Overdone
200° C.	2·5	More overdone
235° C.	1	Spoilt (smoking temperature)

I cannot see how such temperatures can be obtained constantly without thermostatically controlled pans.

Fried egg is generally regarded as indigestible because of a high fat content. Proper frying gives only 12 per cent. as against 10 per cent. in boiled eggs. In badly fried eggs large bubbles may enclose fat, bringing it up to 20 per cent. Loss of weight in a well-fried egg is nil, loss of weight in badly fried egg may be 10 g.; there is 14·5 per cent. P in a well-fried egg, while in badly fried it is 17·28 per cent. The amount of P in a badly fried egg was 7·949 g., whereas in one well-fried egg of the same original weight it was 8·00 g. Thus there is not much actual loss. But 10 g. or 20 per cent. of the former is so badly denatured as to be indigestible. This looks to be the case in *in vitro* digestion experiments.

OMELETS

Only plain omelets have been studied. The standard recipe used was as follows:

2 eggs, 2 teaspoonsful water (20 ml.), pinch salt.

If the pan was seasoned with clarified butter or any other clear fat the omelet lifted clean from the pan, and there was accordingly no waste. The best method for easily digested omelet is to season the pan, and pour off all the fat, adding the eggs to the smoking hot pan, stirring so that they set as quickly as possible. Do not use too hot a flame, otherwise part will become denatured before the rest is cooked. The best omelet is made in 3 mins. The pan must be smooth of surface or the omelet sticks, and there will be considerable waste apart from an unattractive appearance. Pitted aluminium pans were not as satisfactory as smooth well-seasoned iron pans. Coagulation begins at 70° C. and ends at 90° C. Loss of weight is only 1 g. on 127 g., because water only is dried off during the cooking. This also prevents denaturing.

The following table shows the effect of additions on the coagulation time. Texture effects were also noted. Acid tenders the curd

TABLE SHOWING RESULTS OF DIFFERENT WAYS OF COOKING OMELETS

Weight of egg								
Before	After	Age	How beaten	Additions	Coagulation begins	Coagulation ends	Time of cooking	Result
g.	g.							
127	126	Fresh	Lightly	10 ml. water	70° C.	90° C.	3 mins.	Excellent
120	126	Irish	,,	10 ml. water	71° C.	91° C.	3¼ ,,	Flatter
127	126	Fresh	Well	10 ml. water	70° C.	90° C.	3¼ ,,	Good appearance, but flavour "papery"
120	117	,,	Lightly	10 ml. tomato juice	65° C.	90° C.	3½ ,,	Very tender, shrunken
130	126	,,	,,	10 ml. milk	74° C.	94° C.	4 ,,	Does not part with water easily, so tough
130	150	,,	,,	1 oz. margarine melted first in pan	70° C.	90° C.	3 ,,	Good, but not so easy to manipulate. Too high fat

and by changing pH causes earlier precipitation; Freundlich says "peptization may be brought about by hydroxyl ion," so water makes a tender omelet also. With milk, coagulation is different, because different salts are present. This causes toughness.

CUSTARDS, POURING

Recipe: 50 g. egg, 240 ml. (one tea-cup) milk, 50 g. (two tablespoons) sugar.

First the difference between "slow boiling" and "quick boiling" was tested. The custard was cooked in a double boiler starting at cold, then in a double boiler starting at boiling and boiling hard.

TABLE SHOWING GREATER SAFETY OF COOKING POURING CUSTARDS SLOWLY

Temperature	Quick boiling	Slow boiling
80° C.	—	—
81° C.	—	—
82° C.	—	Thickens
83° C.	—	—
84° C.	—	—
86° C.	—	—
87° C.	Thickens	Curdles
88° C.	—	—
89° C.	—	—
90° C.	Curdles	—
91° C.	—	—
92° C.	—	—

Although "slow boiling" sets at a lower temperature, it is found that there is a greater interval of temperature between the "coagulation point" and the "curdling point" than in "quick boiling." This gives a greater margin of safety for the cook.

BAKED CUSTARDS

Custards were then baked to find the best setting temperature. The temperature was taken every 3 mins. Custard was cooked in a basin of water in the oven. It was found as with scrambled egg that coagulation is an endothermic reaction. There is a fall after 92° C. to 86° C., then a rise to 94° C. This last temperature gives a good set. After this there is curdling. By varying the proportions of the different ingredients different setting temperatures are obtained:

RESULTS OF USING DIFFERENT RECIPES FOR BAKED CUSTARD

(1) 1 cup milk, 1 egg, 1 tablespoonful of sugar.
(2) 1 cup milk, 1½ eggs, 2 tablespoonfuls of sugar.
(3) 1 cup milk, 1 egg, 4 tablespoonfuls of sugar.

Temperature	(1)	(2)	(3)
81° C.	—	—	—
82° C.	—	General setting	—
83° C.	—	Good set	—
84° C.	—	—	—
85° C.	Very light set	—	—

Temperature	(1)	(2)	(3)
86° C.	Setting at edge	—	Thicker
87° C.	Set	—	Thicker still
88° C.	—	—	Pouring consistency
92° C.	—	—	Set
95° C.	—	—	—

Thus lowering the sugar lowers the setting temperature to 85° C., increasing it raises the temperature to 92° C. Increasing the egg lowers it to 83° C. By separating yolks and whites still different setting temperatures are obtained.

Setting temperature is thus 89° C. for whites and 92° C. for yolks. Custard made from whites alone was firmer.

CURDLING TEMPERATURES USING YOLK AND WHITE

Temperature	Yolks	Whites
82° C.	Not set, skin	Not set
83° C.	,, ,,	,,
85° C.	,, ,,	Thickening
87° C.	Slight round edges	,,
88° C.	Beginning to set	Thicker
89° C.	Almost set	Set
92° C.	Set	

We found the recipe 1 egg, 1 tablespoonful of sugar (25 g.) and 1 cup milk (240 ml.) the best for serving.

COOKED MAYONNAISE

Recipe: 4 egg yolks, 125 g. (½ tablespoonful) sugar, 240 ml. (one teacup) liquid, 5 g. (½ teaspoonful) mustard, 2·5 g. (¼ teaspoonful) salt.

Ingredients were varied as follows:

(1) ⅛ cup vinegar, ⅞ cup water (30 ml. vinegar, 210 ml. water).
(2) ¼ cup lemon juice, ¾ cup water (60 ml. lemon juice, 180 ml. water).
(3) ½ cup vinegar, ½ cup water (120 ml. vinegar, 120 ml. water).
(4) ⅛ cup lemon juice, ⅞ cup water (30 ml. lemon juice, 210 ml. water).
(5) ½ cup lemon juice, ½ cup water (120 ml. lemon juice, 120 ml. water).

Temperature	(1)	(2)	(3)	(4)	(5)
71° C.	—	—	—	—	Thicker
73° C.	—	—	—	—	Thick
74° C.	—	—	—	Thicker	Good
75° C.	—	Thickening	—	,,	Too thick
76° C.	—	Good	—	,,	Thin
78° C.	Thickening	Thinner	—	Very thick	,,
80° C.	Still thicker	Liquid	Thickening	Too thick	,,
82° C.	Good	,,	Good (thin)	,,	,,
85° C.	Thin	,,	Good	Curdled, thin	Curdled
92° C.	Thin, curdled	Curdled	Good	Curdled	—
95° C.	—	—	Thin	—	—

The table shows that on increasing the vinegar to past the iso-electric point, mayonnaise becomes thinner. It also shows that lemon juice with the citrate ion is more effective than vinegar. It would seem that 60 ml. was less effective than 30 ml. for lemon juice.

Mayonnaise was also made varying the other ingredients, as follows:

(1) Standard as above, plus $\frac{1}{4}$ cup vinegar plus $\frac{3}{4}$ cup water plus 2·5 g. salt; (2) standard as above, plus $\frac{1}{4}$ cup vinegar plus $\frac{3}{4}$ cup water plus 25 g. sugar; (3) standard as above, plus $\frac{1}{4}$ cup vinegar plus $\frac{3}{4}$ cup water plus 72 g. whole egg; (4) standard as above, plus $\frac{1}{4}$ cup vinegar plus $\frac{3}{4}$ cup water plus 2 egg yolks replaced by flour. The results given in the following table show that increasing the salt content or the sugar content lowers the coagulation point. Increasing the egg content or flour content has an even greater effect, as was to be expected.

Temperature	(1)	(2)	(3)	(4)
70° C.	—	—	Thickening	Good
71° C.	—	—	Good	”
72 °C.	—	—	”	”
73° C.	—	—	”	”
74° C.	—	Good	”	Very thick
75° C.	Thickening	Very thick	”	”
76° C.	Good	”	Thick	”
77° C.	Excellent	Solid	”	”
78° C.	”	”	Very thick	”
79° C.	Thinner	Thinner	”	”
80° C.	”	”	Curdled	Solid
81° C.	”	—	”	”
82° C.	”	—	”	”
83° C.	”	—	”	”
84° C.	Very thin	—	”	”
85° C.	”	Very thin	”	”
86° C.	”	”	”	”
87° C.	”	”	”	”
88° C.	”	”	”	”
89° C.	”	”	”	Thinner
90° C.	Thickening	Thickening	”	”
91° C.	—	”	”	”
92° C.	—	”	”	”
93° C.	—	”	”	”
94° C.	—	—	”	”
95° C.	—	—	—	”

MERINGUES

Recipe: 2 eggs (white only), 4 oz. sugar.

After 5 mins. beating, 3 oz. of sugar were gradually added. At the end of beating, 10 mins., the other ounce of sugar is added by folding in. A "Mixmaster" electric whisk was used. Meringues were measured in spoonfuls on to iron trays and cooked in a "Flavel" gas oven, middle shelf, Regulo B.

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We found that cold egg did not beat as well as egg at room temperature. As against 17 meringues at room temperature only 10 were obtained from whites which were beaten after standing in the refrigerator. The number obtained using new laid, day-old, country as bought, Irish, and preserved was found. The effect of adding water and different quantities of salt was also found. Different whisks were tested—"Mixmaster," wire, and hand beater. Effect of drying 24 hours before beating was also tested.

	No.
Effect of age	
New laid	11
Day-old	20
Country	16
Irish	10
Preserved one year (water-glass)	11
Effect of additions—	
Country	17
Country, 2 teaspoonfuls water	12
Country, ½ teaspoonful salt, beating 5 mins.	10
Country, ¼ teaspoonful salt, beating 10 mins.	17
Effect of drying—	
Country	17
Dried	12
Effect of whisk—	
Country eggs, "Mixmaster"	17
,, ,, wire whisk	15
,, ,, beater	12

Whisk—Country eggs

Kind	No.	Appearance
"Mixmaster"	17	Very good
College	15	,,
Beater	12	Too solid

Thus day-old eggs are best. Drying is ineffective unless with new laid or very old eggs, although it led to meringues that had good appearance and beat easily. Addition of salt gave an easily beaten meringue, but it looked overbeaten when cooked. "Mixmaster" gave the best yield for whisk. All the meringues made this way were solid except the lot made by adding the lemon juice to the meringue until it was at the isoelectric point and would not beat. Then soda was added to bring it up again. On this occasion the meringues were hollow. Addition of water did not give the yield expected. Meringues were cooked at 95° C. for 1 hour, they were then dried for 2 hours at 65° C.

Sponge Cakes

Recipe: 2 eggs, 3½ oz. sugar, 2½ oz. flour.

As in meringues, the effect of age of eggs and kind of whisk were investigated. The different kinds of ovens were also tested. Texture was judged by our cookery experts. The volume of the cakes was measured. Time of whisking was 10 min.; the same flour was used throughout.

	New laid cub. in.	Country cub. in.	Irish cub. in.	Duck cub. in.	Preserved cub. in.	Goose cub. in.
Gas oven Wire whisk	51·01	49·05	49·73	59·86	41·01	78·66
Gas oven "Mixmaster"	50·90	45·58	41·59	47·00	—	—
Electric oven "Mixmaster"	43·16	52·72	47·00	—	—	—
Electric oven Wire whisk	51·91	52·44	49·05	54·94	—	—

This gives average volumes (in cu. in.) as follows: country egg, 49·95; new laid egg, 49·02; Irish egg, 46·84; duck egg, 53·87; gas oven, 47·90; electric oven, 49·22; wire whisk, 50·38; "Mixmaster," 46·82; beater, 49·02. Thus country eggs, hand whisk and electric oven would seem to be the best for volume. For texture the experts also voted for the electric oven cake the second day, but we found it dried up considerably by the third, whereas the gas oven cake did not. The experts seemed to prefer the appearance and shape of the gas oven cake.

Digestion Experiments "in vitro"

Different types of egg were digested in an incubator with standard pepsin solution—5 g. of egg and 20 ml. of pepsin were used.

Kind of egg	Hours 10	Hours 20	Hours 30	Hours 40	Hours 50
Hard boiled	0	0	Slight	Slight	Good
Soft boiled	0	Slight	Good	Good	Gone
Poached alone	Very slight	,,	,,	Gone	—
Poached in vinegar	,,	,,	,,	,,	—
Poached egg—salt	0	0	Slight	Good	Gone
Scrambled egg right	0	0	,,	,,	,,
Scrambled egg over	0	0	0	Slight	—
Fried egg, 137° C.	Very slight	Slight	Very good	Gone	—
Fried egg, 235° C.	0	0	Slight	Good	Good

Poached, lightly fried, and soft boiled are the most easily digested forms of egg. Hard boiled eggs are the most indigestible.

Protein and Fat Content of Different Forms of Cooked Eggs

The protein was estimated by the Kjeldahl and the fat by the Soxhlet method.

Protein content—

Boiled	Poached	Scrambled	Omelet	Fried
12·91 per cent.	12·45 per cent.	10·96 per cent.	11·05 per cent.	15·23 per cent.

Fat content—

Boiled	Poached	Scrambled	Omelet	Fried
10·60 per cent.	10·44 per cent.	15·23 per cent.	9·26 per cent.	12·88 per cent.

Thus the protein and fat value of eggs in a diet depend greatly on how they are served.

WASTE OF PROTEIN IN COOKING

Boiled eggs—
None

Scrambled—

Bowl	Pan	Spoon	Shell	Total
1·5 per cent.	6·5 per cent.	3·60 per cent.	1·5 per cent.	13·5 per cent.

Poached—

Residue in pan	Liquid in pan	Shell	Total
2·5 per cent.	3·5 per cent.	1·5 per cent.	7·5 per cent.

Fried correctly—

Shell
1·5 per cent.

Fried at too high temperature—

Shell	Uneatable or indigestible residue	Total
1·5 per cent.	7·4 per cent.	8·9 per cent.

Omelets—

Shell	Bowl	Total
1·5 per cent.	1·5 per cent.	3·0 per cent.

Thus scrambling and poaching are wasteful methods of cooking eggs. Frying may be if too high a temperature is used.

The cost of eggs compared with milk, meat, and fish, for different dietary requirements, taking the average cost at 2s. per dozen, is:

Substance	Milk	Rib roast Meat	Cod White fish	Whole Egg
	s. d.	£ s. d.	s. d.	s. d.
Protein per lb.	6 3	0 8 9	5 11	11 9
Fat per lb.	4 7	0 13 3	—	13 9
Calcium per g. ..	0 4½	1 4 0	12 0	5 0
Phosphorus per 1·5 g. ..	0 6	0 2 0	1 8	3 0
Iron per 0·015 g. ..	2 6	0 4 0	18 0	2 0
Vitamin B 500 units ..	2 6	1 12 0	—	—

Thus eggs are an expensive food except for iron and vitamin B_1.

CONCLUSIONS

Satisfactory cooking of egg dishes is largely a matter of chance by present-day methods. It might be possible to standardize cooking of scrambled eggs, custards, mayonnaise, etc., if thermostatically controlled pans were used. Eggs are usually fried at much too high a temperature because it is impossible to tell the temperature of the fat.

The most digestible forms of eggs, according to *in vitro* experiments, are poached eggs without salt and lightly boiled eggs.

The method of serving eggs should be taken into account when estimating the protein and fat provided by the eggs in a diet.

Waste is greatest in scrambling and poaching eggs but if eggs are badly fried it can be considerable.

Country eggs are best for cooking but at the expensive period they hardly justify their price compared with Irish and preserved eggs. Preserved eggs, which have been over one year in water-glass, are excellent for most forms of cooking, so that preservation of eggs at cheaper periods is well worth while.

Eggs are an expensive food compared with milk, but they are cheaper for mineral salts than meat and an excellent source of vitamin B_1, liable to be deficient in many British diets, as well as a good source of vitamins A and D, riboflavin and nicotinic acid. The yolk is an excellent source of biotin, and cooking entirely destroys the anti-biotin activity of avidin, a protein present in the white.

Part II

THE POTATO AS FOOD

(*Papers read at a meeting on 13th November,* 1940)

CHAPTER VI

THE BIOLOGY OF THE POTATO

By REDCLIFFE N. SALAMAN, F.R.S.

We are frequently reminded that the potato competes with maize for the honour of being the most outstanding gift of the Old to the New World; it may well be so, but Sir Arthur Helps thought that tobacco smoking was perhaps the greatest blessing that we owe to the discovery of America—which only goes to show that the value of a gift depends primarily on the mood of the recipient. To-day we regard everything through the red glow of war, when the problem of the national food supplies and their adequate vitamin and mineral content takes precedence of all else. It is in this sense that the potato steps into the forefront of war-time economics.

It is not due to accident, and still less to the idle interplay of fashion or fancy, that the potato has attained its pre-eminent position in the dietary of the peoples of the temperate zones the world over. Indeed a long uphill fight had to be waged against custom and prejudice which lasted some 150 years before the working people of this country even began to accept it. Its arrival in Ireland corresponded with a time of dire distress and want; the demand for a food easily raised and stored was so insistent that within fifty years the potato had become the staple food of the entire people. Its final victory is due to certain biological characteristics which allow of its almost unlimited adaptation to the requirements of both consumer and environment.

When man first encountered the potato on the Andean Highlands, possibly some 2000–3000 years ago, it was not a single type or individual species that he found, but rather a mixed population of a dozen or more distinct species and a certain number of hybrids which differed from each other in a variety of characters. At the very dawn of Andean civilization man learnt to make use of these variations and selected some for their resistance to frost, some, doubtless, for their better crops or more pleasing taste, and others, later, for their suitability to the manufacture of chuño, a dried product, probably the first preserved food in the world's history, specially designed for winter storage.

At a still earlier date, but probably later than in Peru, man reached the Chilean coast-line and the Isle of Chiloe. Here, at sea-level and in a temperate clime, he met a different group of potato stocks, incidentally more closely resembling our own. Human selection, however unconscious, following closely on that demanded by climatic factors, was based on an important characteristic of potato varieties, viz., their inherent or genetic variability of response to longer or shorter exposure to daylight. Thanks to the recent collections of American potato species made by successive Russian, Swedish, and English botanists, we have come to realize that there are types or species which only form their full quota of tuber material in a short-day environment, i.e., one in which daylight lasts from 8 to 12 hours; whilst others, like our own English varieties, need a daylight of 16 or more hours duration in order to produce the fullest return.

Again, some varieties flower only in a long-day environment, others in a short one, a fact of great importance to-day when crosses between unrelated or distant strains are required in order to introduce new qualities into our potato population.

Most South American potatoes possess fertile flowers from which self-pollinated fruits and seed can be obtained; many of the specific types are fertile *inter se*, thus allowing of a high degree of hybridization. By both methods of fertilization an enormous range of combinations of characters can be obtained. It is more than doubtful whether early American man contrived such, but we do know that many of these crosses have occurred in nature without human intervention.

We shall have occasion later to speak of other genetic characters which have been instrumental in making the potato a universal food, but this wealth of variable characters would have had but little chance of being exploited had not the potato a further outstanding virtue which places it for practical purposes in a class by itself.

All our important vegetables and foodstuff plants such as the cereals, the kales, cabbages, and turnips, are raised each year from seed. Unless the particular plant is homozygous for all the characters which recommend it, no less than for others which may not be apparent, then at each sowing variants appear and the resultant

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crops tend to recede more and more from the selected type. To combat this, it is necessary to be ever on the alert, rogueing and selecting and raising in isolation pure or quasi-pure samples of the desired types. This is a work which the National Institute of Agricultural Botany has made its own, primarily for cereals, but of recent years also for the Brassicae and some of the Leguminosae.

With the potato no such difficulty arises, by reason of the fact that it is propagated by tuber, that is, vegetatively. Any given plant, however hybrid it may be for specific characters, reproduces itself without variation so long as it is grown from the tuber. In other words, once a particular type of plant is selected because of some advantageous quality, that quality is secured at once and for all time by merely planting its tubers from season to season.

By reason of its wide and inherent genetic plasticity, its sexual fertility, and its capacity of immediate fixation of characters by vegetative reproduction, the potato has come to occupy a unique position in the science of horticulture. When, in addition, it is remembered that the potato tuber is readily stored over the winter and spring, it is not surprising that, apart from the cereals, it is our most important storage food.

A survey of the more important variant characters common to the potato throws further light on its adaptability and its economic importance:

Maturity.—We have varieties growing in this country whose range of maturity varies from "earlies" requiring about 100 days' growth in the ground, to "lates" needing some 200 days. Nor is it only our strictly economic requirements which are thus catered for. Man's sheer desire for gain is fostered by the property which some early varieties, such as Epicure, possess to bulk their tubers rapidly, as opposed to others in which the tubers swell more or less steadily throughout the whole period of growth; by skilful exploitation of this quality, growers can make large cash profits when markets are restricted and prices high.

Tuber shape.—Round, long, and kidney-shaped tubers are all the expression of specific genetic factors, and as such can be readily combined with others to suit different tastes.

Tuber eyes.—The depth and size of the bud or eye is controlled by factors independent of shape; the modern breeder makes use of these facts by rearing varieties which both please the eye and avoid unnecessary waste in peeling.

Tuber colour.—Although in practice we confine ourselves to-day to white or pale-red tubers, varieties exist of the deepest purple, beetroot red, or blueish colours. All of these variants are controlled genetically and may be combined with others more definitely desirable for economic reasons. The flesh of the tuber may also be coloured in like fashion, but such are, by popular taste, all but totally excluded from commercial exploitation. The tuber flesh of most of our maincrop varieties in this country is ivory coloured. In Latin countries a yellow flesh is commonly preferred. The yellow-fleshed early varieties, such as Myatt's Ashleaf, Duke of York and, to a lesser extent, Sharpe's Express, are in England popular amongst culinary connoisseurs, though they cannot compete in the markets of the great industrial towns with the heavy cropping, handsome, but insipid tasting varieties, such as Arran Pilot.

Tuber texture.—More important are the variations in tuber flesh texture, exemplified by the floury as opposed to the firm and waxy or soapy types. As to texture, it has not been proved that it is controlled entirely by genetic characters; soil and cultivation certainly play their part.

Protein and carbohydrate content.—The starch content of our English potatoes varies from 15 to 20 per cent. of the fresh tuber weight. In Germany, where starch and, in particular, alcohol, are manufactured from the potato in ever-increasing quantities, varieties with the higher average starch content are preferred. Russian workers hold out hope of obtaining still higher percentages from some of their interspecific crosses, and point out that in certain of the ordinary cultivated Peruvian types the starch content is as high as 25 per cent. Starch content, however, varies sharply with the soil and the season.

The protein content of our domestic varieties is about 2 per cent. to 3 per cent. of the total tuber weight; this, again, varies with the variety. On the Continent, public taste demands a potato with a firm texture, and such has a high nitrogen content. Russian workers claim high nitrogen values in some of their specific crosses.

Vitamin content of the potato.—The potato is a relatively rich and easily acquired source of vitamin C, even if it be poor in others.

Quality.—This is a term which admits of no exact definition and hence of no analysis. Different people imply different things when they use the term. To the large hotel and restaurant caterers, good quality implies a potato whose taste is neither too pronounced nor too insipid. The tuber on boiling must not collapse, nor yet emerge from the pot like a piece of cheese; if mashed it must not blacken for many hours. If possible it should be capable of being re-heated.

Very few varieties fulfil all these demands: the best to-day is King Edward, followed by Golden Wonder and Majestic.

If the potato is "chipped" or "crisped" another quality is demanded: it is required to take a rich gold-brown colour, have a firm to brittle texture and not absorb too much oil in the cooking. Clearly what is a good quality potato for boiling is unlikely to be a good quality "frier." For chips, Majestic is the favourite; for crisps, a Dutch variety known in this country as Bintje.

Much work has been done in attempting to determine the parts played in bringing about this elusive congeries of characters by varietal genetic characters on the one hand, and soil and environmental characters on the other. This work, undertaken by the National Institute of Agricultural Botany, Messrs. J. Lyons & Co. and the writer, has given us some reason to believe that variety plays an important part, and that the effect induced by different soils is significant but difficult to determine. In general, our results have not sustained the popular view as to the virtues of the Lincolnshire oolites or the vices of the Cambridgeshire Fens.

Resistance to disease.—The potato is subject to many diseases, but there are only four whose reactions are sufficiently severe to affect the economic situation. These are:

1. *Wart disease*—caused by a fungus known as *Synchytrium endobioticum* which, in nature, attacks only the potato. The fungus lives in the soil and this, once infected, never becomes free from it, though the organism, whilst resting in the soil, may lose much of its virulence. Wart disease became a serious menace at the beginning of this century when it spread throughout much of the north-west of England and Wales. The fungus attacks the tubers, inducing in them large, warty growths which break down into a putrescent cream. At one time it looked as if the further cultivation of the potato in these regions was threatened till it was discovered in 1908 by Gough that certain varieties were immune to attack. In company with Mr. J. W. Lesley I worked out the genetic factors controlling this resistance, and breeders who had already set to work to create new varieties have since put on the market a number of first-class varieties which can be grown with impunity on the most infected soils. There are few better examples to be found of scientific research being allied to the highly intelligent and skilled ability of the plant raiser to save an important article of the people's food from destruction.

2. *Blight.*—The potato disease which is familiar to all of us, and which descends on the countryside in July or August, in about two

out of every three years, is due to an infection by the fungus *Phytophthora infestans.* This disease first assumed an epidemic character in Europe in 1845, and in that and the following year wrought such havoc that it produced an appalling famine which reduced the Irish population from eight to four millions, whilst its repercussions induced the abolition of the Corn Laws, the Irish emigration to America, the control of New York by Tammany, and the constant fomentation of anti-British feeling from the other side of the Atlantic.

The only method of control in general use is that of spraying the growing plants with copper or other fungicides. Of late, the custom of spraying the infected tops with dilute sulphurious acid, or a mixture of copper sulphate and sulphuric acid, has become general on farms where large acreages of potatoes are grown. Haulms are killed immediately and, if spraying is done in good time, the tubers generally escape infection. After about ten days, the crop is raised. Attempts to breed blight-resistant varieties were first made by myself and subsequently pursued in Germany and Russia. The results are most promising, though the difficulties still to be overcome are considerable. In England this work has received very little encouragement from any quarter; the wholesale trade, in particular, has looked askance at the prospect of an immune potato whose advent would almost certainly lower prices—a crime not readily condoned in the potato world.

3. *Virus disease.*—Under this head one includes a number of diseases which differ clinically but all have much the same effect economically. Virus diseases, at least those which concern us to-day, are due to infection with something, let us call it a "particle"; I intentionally do not use the word "organism." These particles are infinitely smaller than the fungi we have so far discussed and indeed only about one ten-thousandth of the volume of the common *Bacillus coli.* Such particles, which may or may not be living, are conveyed from the sick to the healthy plant by the green-fly. The immediate seasonal effect of infection may not be severe, but the subsequent effect is always so, and in later years the crops grown from infected seed become increasingly crippled and the yields reduced to vanishing point. Once infected, a plant never recovers and, generally speaking, all the tubers of an infected plant are themselves infected. Within a given area the disease has a progressive and cumulative action.

The annual loss in Great Britain due to virus disease till some fifteen years ago was estimated at 30 per cent. of the potential crop; this means nearly two million tons per annum which, at present prices, would be worth about £15,000,000. To-day, the work of our Virus Research Stations has induced in both the authorities and the public a much greater awareness of the advantage of using good, i.e., virus-free, seed. As a consequence, the loss of potential crop has been very materially reduced. It is difficult to say when this disease was first introduced; it is conceivable, but unlikely, that it came with the potato at the time of its introduction at the end of the sixteenth century. In England it has been a serious trouble since about 1770. The only control we know so far is the provision of virus-free potato seed. As the disease is conveyed by the green-fly, those parts of the country in which the fly is less prevalent or, what is still more important, the winged form less mobile, are those in which the healthiest potatoes are raised and in consequence those where the best seed is produced. Speaking roughly, Scotland and Ireland are more favoured localities than England. As a result, a mystic value has been attributed to potatoes emanating from Scotland and has been exploited to the full. Some Scotch seed is very good, much is fair, but not a little is very poor. Many of our growers still, however, imagine that because their seed stocks are labelled "Scotch" they are *ipso facto* good: it is a dangerous mistake; they should demand seed which has been duly examined by the Department of Agriculture for Scotland and certified either as stock seed, or under the letters "A" or "H". No seed of lesser quality than these is allowed to be exported from either the North or the South of Ireland.

A great deal of excellent research has been done on the virus diseases themselves and their transmission. As a result the lines on which the national cultivation of the potato could be built up with a very favourable chance of completely avoiding virus troubles can be laid down. The first steps in the campaign I took some sixteen years ago, whilst Director of the Potato Virus Research Station, Cambridge, by collecting nuclear stocks of virus-free varieties and maintaining them under insect-proof conditions. The next step taken was to show that such stocks could be maintained relatively free from disease in the open if only they be planted in sufficient isolation from other potatoes. The third was to draw up a plan by which such could be done on a rotation system for the United Kingdom. This plan was presented in detail to the Potato Marketing Board six years ago, and again at subsequent intervals, but more particularly in the July preceding the outbreak of war. That body, the Ministry of Agriculture, and other public organizations, have toyed with the idea ever since, with varying degrees of impatience. Now, when there is a demand for the largest possible production of potatoes per acre, the shortage of really good seed is becoming apparent even to the trade. In 1940 the Ministry became mildly interested once more, and indeed are making use of these virus-free stocks, but not in the manner I advocated and still consider the only effective one.

Since 1917 a new scourge has appeared in our potato fields. I refer to the attacks on the potato root of eel-worm, *Heterodera rostockiensis*, formerly *schachtii*, the spread of which is becoming increasingly serious. In areas in which potatoes are one of the chief recurrent crops, the infection is having a marked effect on output. So far, neither an effective treatment nor a variety resistant to *Heterodera* has been discovered. Heavily infested land should be rested from potatoes for five years or longer. Potatoes should not be grown more frequently than once in four years.

If one is right in assuming that the potato is one of our most vital bulwarks against want in time of war, then I am convinced that the conversion of the potatoes of this country from a mixed healthy, quasi-healthy, and virus-infected crowd into a high-yielding healthy population ranks amongst the most urgent of our war tasks. The key to the solution we possess to-day ; it is the propagation of virus-free tuber-seed. We have the knowledge, the right plan, the necessary material ; all we need is the courage and intelligence to make use of them. To complete such a task would take five or six years' intensive administrative and technical work. Much progress could have been effected had the Potato Marketing Board taken action in July, 1939. It is still not too late to recover some of the lost ground. Since this chapter was first written, the National Institute of Agricultural Botany are engaged in multiplying these virus-free stocks in Northern Ireland.

CHAPTER VII

THE CHEMICAL COMPOSITION OF THE POTATO

By L. H. Lampitt and N. Goldenberg

The composition of the potato has in the past received considerable attention from chemists, but unfortunately many of the observations reported have been either fragmentary or directed towards clearing up some isolated problem and but few of them can be classed as fundamental. The relevant information is spread over a vast literature and it has not been easy to sift the available data in order to present a complete picture of the present knowledge of the composition of the potato and of the changes taking place when it is cooked.

In common with other workers in the field of biochemistry, the investigator of the composition of the potato has to recognize the non-static nature of the raw material; it is changing throughout its period of growth as well as during storage after it has been lifted from the ground. Variety, age and conditions of growth are but some of the variables; indeed, one worker (Goldthwaite[1]) has shown that no two individual tubers of the same variety are identical in composition, even when taken at the same time from the same "hill," a fact confirmed by our own observations. Nevertheless, the variations for normal potatoes fall within fairly well-defined limits. (It is perhaps necessary to point out that the methods of analysis used by the different investigators are not necessarily the same, and some of the variations observed may well have been due to this further complication. Discussion of analysis is, however, outside the scope of this paper and one can only assume that the more recent the investigation, the more likely are the methods of analysis employed to have been the best.)

Very few of the investigators have standardized their technique. For instance, some of the analyses have been carried out on peeled potatoes, i.e., on the edible portion only, but in many instances there is no indication whether peeled or unpeeled potatoes were used, and here it has been assumed that the entire potato has been the subject of the investigation. One of the important conclusions emerging from the present survey of the literature is that it is highly desirable

Ref.	Investigator or source	Year pub.	% Water		% Starch		% Carbo-hydrates†		% Protein*		% Ash		% Fat		% Crude fibre	
			Av.	Variations	Av.	Variations	Av.	Variations	Av.	Variations	Av.	Variations	Av.	Variations	Av.	Variations
4	Langworthy‡	1917	—	78·3	—	—	—	18·4	—	2·2	—	1·0	—	0·1	—	0·4
13	Leach	1920	—	66·1–80·6	—	—	—	16·0–30·5	—	1·43–2·81	—	0·44–1·18	—	—	—	0·37–0·68
14	Russell	1920	77·9	70·9–82·4	—	—	—	—	2·04	1·27–3·29	—	—	—	—	—	—
		1920	77·6	73·7–81·7	—	—	—	—	1·93	1·27–2·63	—	—	—	—	—	—
		1920	76·1	72·7–77·9	—	—	—	—	2·44	1·97–2·86	—	—	—	—	—	—
15	Headden	1924	80·0	79·2–81·3	—	12·9–16·1	15·6	13·3–16·6	2·62	2·31–2·77	1·03	0·94–1·10	0·09	0·07–0·12	0·51	0·42–0·56
		1928	—	78·8	—	14·6	—	15·9	—	2·74	—	1·02	—	0·09	—	0·50
1	Goldthwaite	1925	77·2	72·4–81·9	16·0	11·4–21·8	19·8	13·9–25·6	2·02	0·87–3·19	0·96	0·63–1·52	—	—	—	—
		1925	77·1	73·6–80·5	15·4	13·6–17·7	19·5	16·7–22·6	2·31	1·79–3·11	1·07	0·87–1·29	—	—	—	—
		1925	—	78·1–80·5	—	14·1–16·0	—	17·1–19·1	—	1·69–1·90	—	0·71–0·82	—	—	—	—
16	Rehwald	1926	74·9	68·0.84·9	—	—	20·9	19·5–22·6	1·99	0·69–3·67	1·09	0·53–1·87	—	0·04–0·96	0·98	0·28–1·57
17	Poplawski	1931	—	78·7	—	—	—	—	—	1·50	—	—	—	—	—	—
11	Chatfield and Adams‡	1931	77·8	66·0–85·2	14·7	12·1–16·4	—	—	2·0	0·9–3·9	0·99	0·5 –1·9	0·1	0·0 –0·3	0·4	0·2 –0·9
		1931	79·2	77·1–81·3	16·1	11·4–23·7	—	—	—	—	—	—	—	—	—	—
18	Wright	1932	—	79·2–80·0	—	14·4–15·2§	—	—	—	—	—	—	—	—	—	—
19	Schrader	1933	77·4	72·0–82·2	—	—	19·1	14·4–24·6	1·66	1·37–2·20	1·01	0·87–1·19	0·06	0·03–0·19	0·61	0·50–0·76
20	Moor and Partridge	1934	74·0	—	—	—	22·9	—	2·0	—	1·00	—	0·15	—	—	—
8	Rathsack	1935	—	71·8–81·0	—	12·3–20·3	—	—	—	—	—	—	—	—	—	1·20–2·58
22	Winton and Winton	1935	78·9	75·4–82·2	—	—	17·4	14·1–20·4	2·14	1·14–2·98	0·95	0·78–1·16	0·10	0·02–0·18	0·56	0·28–0·85
		1935	78·3	67·8–84·0	—	—	18·4	13·3–26·5	2·2	1·1 –3·0	1·0	0·5 –1·9	0·1	0·0 –0·2	0·4	0·2 –0·9
		1935	—	76·9–81·1	—	14·9–17·1	—	—	—	—	—	—	—	—	—	—
		1935	76·6	71·9–80·3	17·9	14·0–22·5	—	—	—	—	—	—	—	—	—	—
		1935	77·9	67·5–84·6	16·4	10·2–23·3	—	—	—	—	—	—	—	—	—	—
		1935	—	80·0	—	14·3	—	—	—	1·86	—	0·88	—	—	—	0·52
23	Stuart and Appleman	1935	—	—	—	—	—	—	—	1·83–2·68	—	—	—	—	—	—
24	Sweetman‡	1936	—	78·0	—	—	—	18·8	—	2·2	—	0·9	—	0·1	—	—
25	Mangold	1936	—	72·0–82·2	—	—	—	14·6–24·6	—	1·4 –2·2	—	0·87–1·18	—	0·02–0·18	—	0·49–0·76
26	Metzger	1938	—	75·7–80·0	—	13·2–18·0	—	—	—	2·13–2·52	—	0·88–1·02	—	—	—	—
27	Singh and Mathur	1937	—	80·8	—	13·4	—	—	—	2·37	—	1·3	—	—	—	0·33
28	Imp. Bureau Animal Nutrition	1938	—	—	—	—	—	18·7–20·4	—	1·6 –1·9	—	—	—	Trace	—	—
29	Wachholder	1938	—	—	—	13·9–17·8	—	—	—	—	—	—	—	—	—	—
30	Stevenson	1939	75·8	74·2–78·6	13·5	11·7–14·7	—	—	—	—	—	—	—	—	—	—
		1939	76·6	74·0–78·5	12·4	9·9–14·5	—	—	—	—	—	—	—	—	—	—
31	Titus	1939	—	78·8	—	—	—	18·2	—	2·0	—	0·9	—	0·1	—	0·5
33	Nikolaev	1939	—	—	—	16·0–22·4	—	—	—	—	—	—	—	—	—	—
32	Nash and Smith	1940	—	79·0	—	14·7	—	—	—	2·02	—	—	—	—	—	—
10	McCance and Widdowson‡	1940	75·8	—	18·3	—	22·9§	—	2·1	—	—	—	Trace	—	—	—
34	Carpenter	1940	—	75·9	—	20·8	—	22·9	—	1·3	—	0·72	—	0·11	—	—
		1940	—	79·3	—	18·4	—	19·2	—	2·0	—	0·64	—	0·10	—	—
35	Arutyunyan and Arutyunyan	1940	—	71·0–77·6	—	16·8–22·1	—	—	—	1·53–2·61	—	0·87–2·2	—	0·1 –0·33	—	0·23–0·94
36	Brautlecht	1940	—	81·0	13·4	10·6–15·4	—	—	—	—	—	—	—	—	—	—
37	Nash	1941	—	74·2–83·7	—	11·4–19·3	—	—	—	1·23–2·64	—	—	—	—	—	—
38	Marston and Dawbarn	1941	—	75·8	—	—	—	20·8§	—	2·1	—	—	—	—	—	—
39	Anonymous	1942	78	—	—	—	16·2	—	1·2	—	—	—	—	—	—	—
40	Smith and Nash	1942	74·8	72·5–81·9	—	—	—	—	—	—	—	—	—	—	—	—
7	Neuberger and Sanger	1942	—	78·0–82·2	—	—	—	—	—	1·50–2·25	—	—	—	—	—	—
12	Woodman and Evans	1943	—	76·2	—	—	—	19·7	—	2·1	—	1·0	—	0·1	—	0·9

Notes:—* The protein is given as (Total N × 6·25) for the reasons explained in the text. † Or % Nitrogen-free extractives.
‡ Analyses refer to the edible portion only. § Reported as dextrose.

that any analysis of potatoes should state clearly whether the potato has been peeled or not, and if so, what proportion of the potato has been discarded in the process. Failure to realize the importance of this point may also have led to further and unnecessary variations in the reported results on the composition of the tuber.

It may be remarked here that several hundreds of samples of potatoes were analysed by us during the course of collaborative work with the Rothamsted Experimental Station in 1929–30. Our standard method of preparing samples for analysis is as follows:

> The potatoes are wiped gently with a dry cloth to remove any adhering soil, cut into thin slices (0·9) mm.) and dried in a vacuum oven at 60° C. (vacuum 24 in. Hg.) for seven hours, the dried material being subsequently ground in a mill.

THE MAJOR CONSTITUENTS OF THE POTATO

The constituents classed under this heading include water starch, various nitrogenous substances, sugars, pectins, fat, ash and crude fibre. The results obtained by the various investigators are collected together in Table I and are commented on separately below. The somewhat indefinite fraction determined by many workers as "nitrogen-free extractives" or "carbohydrate" corresponds in effect to the sum of the starch, sugars and pectins. The protein of the potato corresponds only to some 30 to 60 per cent. of the total nitrogen (see below), but most workers have determined only the total nitrogen and reported it as protein (Total N × 6·25). For the sake of uniformity, the same practice has been followed here.

The Different parts of the Potato

A number of investigators have determined the proportions of the various parts of the tuber; the results obtained are given in Table II.

TABLE II

Investigator or source	Ref. No.	Year	Per cent. of the whole tuber in :— Skin	Cortex	External medulla	Internal medulla
Coudon and Bussard ..	5	1897	8·8	36·2	37·6	17·4
Frisby and Bryant ..	6	1897	11·0	89		
Glynne and Jackson ..	2	1919	4·7	38·7	36·9	19·7
Small tubers ..	2	1919	2·8	52·2	31·3	13·7
Medium tubers ..	2	1919	1·9	40·4	36·4	21·3
Large tubers ..	2	1919	2·8	37·0	40·0	20·2
Neuberger and Sanger	7	1942	1·5–5·0	35–45	35·4	25·7

Although comparison of the analytical results for peeled and unpeeled potatoes (Table I) does not reveal any outstanding difference between them,* results obtained more recently by Woodman and Evans[12] have shown that this is because the true peel forms only a very small proportion of the total. Peelings removed by hand were of approximately the same composition as the original whole potatoes, but mechanical peeling removes an exceedingly thin skin, which is richer in ether-soluble matter, fibre and calcium, but poorer in carbohydrate (Table III.) The proportion of the peelings removed has been reported by a number of investigators[4,9,10,11] as varying between 3 per cent. and 25 per cent. of the whole tuber, average figures being 14 per cent. to 16 per cent. These figures show that the part usually discarded as peel may represent quite a considerable part of the tuber and include part of the cortical layer.

TABLE III

COMPOSITION OF POTATO PEELINGS (DRY BASIS)

	Peelings obtained by hand-peeling Per cent.	Peelings obtained by mechanical peeling Per cent.	Original whole potatoes Per cent.
Crude protein ..	9·94	9·15	8·82
True protein ..	6·97	8·03	6·72
Ether extract ..	0·35	7·21	0·42
N-free extractives	80·3	60·4	82·8
Crude fibre ..	3·44	16·9	3·78
Ash	5·93	6·38	4·20
CaO	0·18	0·90	0·13
P_2O_5	0·45	0·35	0·76
Cl	0·32	0·18	0·17

Glynne and Jackson[2] (whose work has been subsequently confirmed by Goldthwaite[1]) have shown that the different zones of the tuber vary in composition; thus the percentage of dry matter is lowest in the skin, increases to the cortical layer and then decreases towards the centre of the tuber. The percentage of nitrogen in the fresh material decreases from the skin to the cortical layer and then increases in the medullary zone, its distribution following that of the water. This is not unexpected, since nearly all the nitrogen of the potato is present in a water-soluble form. The starch granules are more numerous in the inner cortical layer. Stuart[3] and Langworthy[4] have stated that the cortical layer contains a higher percentage of soluble carbohydrates, soluble nitrogenous matter and acids than the entire tuber. Rathsack[8] found that from the outside to the inside of the tuber the total solids and the starch first rise to a maximum and then fall, whilst the total nitrogen, the soluble nitrogen and the amino-nitrogen first fall to a minimum and then rise again.

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* Analyses of peeled potatoes have been marked * in Table I.

The Water of the Potato Tuber

The extreme values obtained range from 66 per cent. to 85 per cent. of the tuber, but the actual average values fall within the range 74 per cent. to 81 per cent. Our own results show variations from 68 per cent. to 81 per cent. It is of interest[41] that wild species of potato from Central and South America possess a much lower water content (61 per cent.). Dumanski[42] has shown by refractometric methods that 1 g. of the dry substance of raw potato binds to itself 0·57 g. water. On freezing, the "bound water" fell to 0·34 g. per g. dry solids and on drying to 0·54. Greathouse[43] has obtained similar results on freezing; the percentage of the total water present in an unfreezable form (i.e., "bound water") fell from 11 per cent. at − 10° C. to 5·6 per cent. at − 23° C.

The Starch

The extreme values obtained range from 10 per cent. to 24 per cent. of the tuber, whilst the actual average values fall within the range 12 per cent. to 18 per cent. Starch contents as low as 8·7 per cent. have, however, been observed,[22] and Radley[44] mentions that German potatoes have starch contents of 25 per cent. to 40 per cent. Starch content depends considerably on local environment. Periodical shading of the tubers during growth markedly reduced the starch content.[32]

The starch content of potatoes has a high degree of correlation with the total solids content and also with the specific gravity of the tubers,[21] and, in fact, the S.G. of potatoes is often used to obtain an approximate value for the starch content.

The composition and constitution of potato starch have been the subject of a large number of investigations; the analytical characteristics usually recorded are summarized in Table IV; it should, however, be pointed out that, in the commercial preparation of potato starch, the smallest granules are lost if sedimentation processes are involved[45] and the resulting starch may therefore differ

TABLE IV

THE COMPOSITION OF POTATO STARCH (DRY BASIS*)

	Ref.	Maximum variations Per cent.	Average values Per cent.
Moisture	49	11·9–22·0	18–22
Ash	50	0·13–0·43	0·15–0·38
Nitrogen	51	Nil–0·38	0·01–0·07
Phosphorus	52	0·04–0·15	0·07–0·11
Silicon	53	0·002–0·04	–
Fat	54	0·02–0·04	–
Uronic acid residues	55	Nil	–

* Where the moisture content was not given, it has been taken as 20 per cent.

from the starch in the tuber. There is evidence that the larger granules of potato starch differ in composition from the smaller granules. Corvaisier[46] found the smaller granules to have a higher ash content, whilst Samec[47] and Richardson[48] both found them to contain more phosphorus, than the larger granules.

There is little evidence on whether potato starches from different varieties of potatoes have identical properties. Kavcic[56] has shown that some of the physico-chemical properties are substantially the same in starches from four varieties (per cent. P, per cent. ash, temperature of gelatinisation, viscosities of pastes and sols, iodine absorption, per cent. of pastes and sols in dialysable form). Similar comparisons have been made by Ostanin,[57] who has also shown that the per cent. ash, per cent. P and size of the granules increase on ripening.[58] Different varieties of potato starch (saccharified at different rates and to different degrees by diastase[33]) yielded pastes of different viscosities. The conditions of growth affect the viscosity and the granule sizes. According to Veselovsky,[59] the ratio of large to small granules is a varietal characteristic. A positive correlation was obtained between the ash content, the phosphorus content and the viscosities of 0·3 per cent. pastes for a number of potato starches obtained from different varieties of potatoes.

In spite of a considerable number of investigations, summarized by Samec,[47] and later by Samec and Blinc,[60] and by Lampitt, Fuller and Goldenberg,[61] little definite is known about the form in which phosphorus is present in potato starch. Posternak[62] has concluded that the phosphorus of potato starch is bound to the polysaccharide as a phosphoric ester at the C_6 carbon atom of the anhydroglucose rings in the starch macromolecule ; Janicki[63] came to the conclusion that only some 10 per cent. was so bound and that the remainder was present in the form of adsorbed inorganic phosphates.

It has not yet been possible to obtain conclusive evidence whether or not granules of potato starch are surrounded by a thin non-starchy envelope,[64,65,66] but the trend of modern thought is that this is not so.[67] Meyer and his co-workers[68] have shown recently that potato starch (as well as other common starches) contains two kinds of starch macromolecules, some 18 per cent. consisting of straight-chained macromolecules (molecular weight about 40,000), and the remainder of branched macromolecules of much higher molecular weight. These results have recently been confirmed independently by Hassid and McCready.[69] These two starch fractions differ markedly in their physical and chemical properties.[70]

The straight-chained component is similar in many respects to the "synthetic" starch obtained from glucose-1-phosphate by means of phosphorylase, an enzyme present in the raw tuber.[71]

The industrial use of potato starches has led to a number of studies on the physico-chemical properties of this constituent of the tuber (cf. Radley's *Starch and its Derivatives*[44]). It is interesting that (under comparable conditions of preparation) potato starch gives pastes of much higher viscosity than any of the other common starches[72]; this high viscosity falls very rapidly when the pastes are stirred or agitated, the rate of fall being greater than with pastes of other starches.

Goldthwaite[1] has suggested that the following average ratios are approximately true:

Starch : Dry Solids = 1 : 1·42.
Starch : Total carbohydrate = 1 : 1·24.

Fats and Fat-like Substances

Fat is present only in very small quantities (extreme limits Nil to 1·0 per cent.; narrower limits* 0·06 per cent. to 0·15 per cent.). It has recently been shown by Kroner and Volksen[73] that the ethereal extract of potatoes contains linolenic and linoleic acids, the crude fat being from 0·06 per cent. to 0·1 per cent. of the tuber. In a further paper,[74] Kroner and Wegner have investigated the organoleptic substances present in the tuber. These are volatile in steam, and contain (in addition to the fatty acids mentioned above), a pentanol and a sulphur-bearing compound or compounds. The higher fat content (7·2 per cent.) of the peel has already been noted.[12] A phosphatide-like compound has also been extracted from potatoes.[75]

Crude Fibre

Crude fibre is present in relatively small quantities in the potato tuber (extreme limits 0·2 per cent. to 2·6 per cent.; narrower limits 0·3 per cent. to 1·0 per cent.). According to a recent investigation,[76] potatoes contain no water-soluble hemicelluloses, 0·2 per cent. water-insoluble hemicelluloses and 0·36 per cent. cellulose.

Nitrogenous Substances

The extreme values obtained for the total nitrogen content of the tuber (as N × 6·25) range from 0·7 per cent. to 4·0 per cent., whilst the actual average values fall within the range 1·7 per cent. to 2·6 per cent. Wild species of potatoes have been reported to contain 4·5 per cent. to 5·0 per cent.[41] The nitrogen present in the potato tuber is due only partly to protein, the remainder being present as free amino acids, organic bases, etc. These will be considered separately.

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* The narrower limits have been obtained by elimination of the more isolated values recorded.

(*a*) *The protein component.*

The protein of the potato has been reported to constitute about 50 per cent. of the total nitrogen content.[23,24,77,78,79,80] More recently, Neuberger and Sanger[7] have reported 28 per cent. to 58 per cent. of the total nitrogen content as being present in protein form, whilst Chick and Cutting[81] have obtained a figure of 38 per cent. This protein is a globulin, which is soluble in very dilute salt solution and is present almost entirely in the juice.[22,24,82] It has been called "tuberin," and can be separated quantitatively from potato juice foaming.[83] It is an acid protein.[82] Tuberins from different varieties of potatoes have different heat coagulation temperatures (71° C. to over 100° C.), possibly because they differ in degree of ionization. Kon[78] found tuberin to contain 14·8 per cent. N, 1·1 per cent. S and 1·8 per cent. ash, whilst Ross and Tottingham[84] found 14·0 per cent. N and Kiesel[85] found 16·0 per cent. N in which 1·0 per cent. was due to amide N, 8·1 per cent. to α-amino N and 0·49 per cent. to cyclic N. The amino acids and other nitrogenous compounds so far identified in tuberin are set out in Table V.

TABLE V

COMPOSITION OF THE PROTEIN OF POTATO (TUBERIN)

	Kiesel[85] Per cent.	Ross and Tottingham[84] Per cent.	Winton and Winton[22] Per cent.
Tyrosine	3·63	5·37	4·3
Lysine	—	—	3·3
Cystine	—	—	4·4
Histidine	2·1	—	2·3
Arginine..	6·49	—	4·2
Tryptophan	—	0·52	—
Proline	4·03	—	3·0
Alanine	—	—	4·9
Valine	—	—	1·1
Leucine	—	—	12·2
Glutamic acid	—	—	4·6
Phenylalanine	—	—	3·9
Ammonia	—	—	1·8

(*b*) *Free nitrogenous bases.*

Histidine, lysine, arginine and tyrosine[22] are believed to be present in the juice, whilst Sweetman[24] states that arginine and leucine are also present. According to Alten and Orth[86] potatoes contained 0·08 per cent. to 0·18 per cent. free arginine and 0·19 per cent. to 0·54 per cent. total arginine (dry basis). Isherwood[87] has identified the free tyrosine present as *l*-tyrosine and found it to constitute 15 mg. per 100 g. fresh weight. Tryptophan is also present in small quantity, together with some phenolic compound closely allied to tyrosine. Robinson[88] found tyrosine to constitute 8 to 60 mg. per 100 g. of the tuber, whereas Nash and Smith[32] found 27 mg. Laland[89] has observed that unripe potatoes contain narcotine and the presence of acetylcholine has been noted.[90] The results of more detailed investigations by Yoshimura[79] and by Neuberger and Sanger[7] are summarized in Table VI.

TABLE VI

NITROGENOUS BASES IN THE POTATO TUBER

Base	Neuberger and Sanger	Yoshimura	Other investigators*
Asparagine ..	Present	—	—
Glutamine ..	,,	—	—
Tyrosine ..	,,	—	Present
Arginine ..	,,	Present	,,
Leucine ..	,,	—	,,
Phenylalanine	,,	—	—
Adenine ..	,,	Present	—
Trigonelline ..	,,	,,	—
Choline ..	,,	,,	—
Lysine ..	Not found	,,	Present
Histidine ..	,,	,,	,,
Cystine ..	,,	—	—
Trytophan ..	,,	—	Present
Hypoxanthine	,,	Present	—
Cadaverine ..	,,	,,	—
Xanthine ..	—	,,	—
Guanine ..	—	,,	—

* Referred to in detail in the text.

(c) *Different forms of nitrogen.*

Poplawski[17] found that in addition to 48 per cent. to 67 per cent. of the total N being from protein, 10 per cent. to 13 per cent. is amino-N, and 15 per-cent. to 24 per cent. amide-N. According to Neuberger and Sanger[7], asparagine-N forms 12 per cent. to 27 per cent. of the total N, the glutamine-N 7·6 per cent. to 19·7 per cent., the α-amino N 6·4 per cent. to 12·8 per cent. and the basic-N 20 per cent. to 28 per cent. Chick and Cutting[81] have reported that amide-N forms 22 per cent. of the total nitrogen, amino-acid N 10 per cent. and basic-N 25 per cent. Nash and Smith[32] report the non-protein nitrogen to constitute 78 per cent. and the α-amino nitrogen 52 per cent. of the total nitrogen. Headden[15] has published two extensive but rather diffuse investigations on the effect of nitrate fertilizer on the composition of potatoes, in the course of which the following fractions were investigated :—ammonia-N, amino-N, amide-N, albumin-N, peptone-N, nitric-N and proteose-N. The following figures (Table VII) have been calculated from some of the published results:

TABLE VII

DIFFERENT FORMS OF NITROGEN IN THE POTATO

Total nitrogen	0·22–0·43	per cent.
Albumin nitrogen*	24–45	per cent. of the total nitrogen.
Proteose nitrogen*	2–15	,, ,, ,, ,,
Peptone nitrogen*	6–13	,, ,, ,, ,,
Nitric nitrogen*	0–1	,, ,, ,, ,,
Ammonia nitrogen	78–118	p.p.m.
Amide nitrogen	288–531	,,
Amino nitrogen	646–984	,,
Nitrite nitrogen	Trace– 12	,,

* Calculated figures.

(*d*) *Effect of storage, variety, etc.*

It has been found[23,80] that the nitrogen content of potatoes is unchanged on storage, although at 130° C. Poplawski[17] reports that the total N decreases relatively to the total solids. Potatoes subjected to cold storage contained more amino and amide nitrogen than those subjected to warm storage. Stuart and Appleman[23] have shown that the relative proportions of the different forms of nitrogen do not change on storage at 2 to 3° C for a considerable time. The sprouts formed are richer in total nitrogen but poorer in basic nitrogen than the potatoes from which they have developed.

The total nitrogen content of potatoes appears to depend more on the environmental conditions than on variety,[19,37,91] but the protein content may vary according to conditions of culture.[26] Neuberger and Sanger[7] found that variety was an important factor in determining the distribution of nitrogen and of the different forms of nitrogen in the tuber. Total nitrogen is high in the peel, decreases sharply in the cortex and rises again towards the pith. All the forms of nitrogen investigated are also unevenly distributed throughout the tuber. However, Stuart and Appleman[23] find much smaller differences.

Nash and Smith[32] have observed that potatoes subjected to periodic shading during the maturing period contain more soluble and α-amino nitrogen and less protein nitrogen than those allowed to grow normally. The tyrosine content also increased. Russell[14] found that potatoes immune from wart disease have a higher total nitrogen content than those not immune and Alten and Orth[86] observed a relationship between the total nitrogen content and susceptibility to infection by *Phytophthora infestans*.

Nitrogenous fertilizers have been observed to increase the nitrogen content of the tuber.[92]

(*e*) *Solanine.*

A number of investigations have been reported, some of them quite recent, on the presence of the toxic glycoside solanine in potatoes. Solanine is composed of 1 molecule each of the alkaloid solanidine ($C_{27}H_{43}ON$) and the sugars dextrose, galactose and rhamnose.[93,94] Free solanidine is not present in the normal tuber[95] but has been found in some (though not all) sprouts[96]; abnormally high contents of solanine have been found in potatoes exposed either to direct sunlight or to ultra-violet light[96,97,98,99,100] and unripe potatoes contain more than mature ones.[100,101] The outer layers of the tubers, and particularly the skin, are richer in solanine than the inner part.[96,97,98,99,100] It has been suggested[102] that solanine may be concerned in the process of sprouting.

The recorded values for normal and abnormal potatoes are summarized in Table VIII.

TABLE VIII

THE SOLANINE CONTENT OF POTATOES (MG. PER 100 G).

Source or investigator	Normal potatoes	Abnormal potatoes
Winton[22]	2 – 9	28–58 79 10–40
Valentin[103]	2·7– 4·6	—
Gortner[93]	2·4	—
Willimott[101]	2·7– 9·1	—
Cox[104]	2 –10	over 25
Lampitt *et al.*[95,96]	1·2–10·0	—
Arutyunyan[99]	2·9–10·1	—
v. Fellenberg (peeled)[98]	0 – 2·6	11–22
v. Fellenberg (whole)[98]	—	24–46

The solanine content of potatoes increases on storage (except at 4° C.) because of the very high concentration of solanine in the sprouts that then develop.[96] The increase is greater when potatoes are stored in the light than when they are stored in the dark.[96,98] Arutyunyan[99] fonud, however, that storage at − 6° to − 8° C. does not affect the solanine content and Naumov[105] observed that solanine increases on storage at low temperatures but decreases at 5° to 7° C. Potatoes grown from solanine-rich tubers contain much less solanine than the original tubers[103,106]; after two seasons the solanine content becomes normal.[103] When the same variety of potatoes is grown in hot and cold climates, that grown in a hot climate contains more solanine.[99]

The results obtained by Lampitt and his co-workers[95,96] on the various parts of the tuber and also of the plant are given in Table IX. They were obtained by an improved method of determination.[95]

TABLE IX

Distribution of solanine in the potato plant (mg. per 100 g.)

Part of plant	On original material	Calc. on a dry basis
Skin (2 to 3 per cent. of tubers)	30 – 64	106– 270
Peel (10 to 12 per cent. of tubers)	15	66
Peel (including eye)	30	130
Peel (excluding eye)	19	83
Flesh	1·2– 10	6– 40
Whole potato	7·5	27
Sprouts*	420 –730	565–4070
Flower	215 –415	1580–3540
Leaf	55 – 60	510– 620
Stem of haulm	2·3– 3·3	25– 55

* Formed by irradiation in ultra-violet light.

It is clear from the results given here that peeling potatoes will remove a considerable part of the solanine contained in the tubers, a point of some importance. Some of the solanine is also leached out on cooking.[103]

Sugars

The quantity of sugars in potatoes is greatly influenced by storage temperatures and, depending on the conditions used, potatoes may contain 0·2 per cent. to 6·8 per cent. sugars.[18,107] According to Bois and Savary,[108] sucrose and invert sugar but not maltose are present in tubers. The quantities found in normal potatoes are given in Table X.

TABLE X

The sugar content of potatoes

Investigator or Source	Reducing sugar Per cent.	Sucrose Per cent.	Total sugar Per cent.
Wright[18]	0·9 –2·0	0·27–0·3	1·2 –2·3
Nikolaev[33]	—	—	1·3 –2·3
Singh and Mathur[27]	0·05	0·14	0·25
Wright[109]	0·2 –0·35	0·5 –0·6	0·7 –0·9
Nelson[110]	—	0·1–0·3	—
Hanes and Barker[111]	0·04	0·09–0·12	—
Barker[107]	—	—	0·2 –0·5
McCance *et al.*[10]	0·3	0·2	0·5
Carpenter[34]	0·7	0·7	1·4
Arutyunyan and Arutyunyan[35]	1·0 –2·2	0·3 –0·9	—
Chatfield and Adams[11]	—	—	0·2 –1·5

Changes in Sugar Content on Storage

During the storage of potatoes, the following processes take place[93]:

(1) Starch ⟶ sugar
(2) Sugar ⟶ starch
(3) Sugar ⟶ carbon dioxide + water (respiration).

When the temperature is lowered, the rates of all these reactions are unequally decreased, so that more sugar is accumulated. Below

4·5° C., more sugar is produced, whilst at 0° C. 3 per cent. sugar is the equilibrium concentration. Many workers[112,113] have studied the increase of sugar on storing potatoes at low temperatures but few of these investigations were in any way fundamental. Accumulated sugar can be greatly decreased by transferring the potatoes to a higher temperature,[113,114] at which it is presumably used up in respiration. It is noteworthy that sugar formation can take place even at – 20° C. in the hard frozen tuber.[115] Hanes and Barker[111] have obtained evidence that the production of sugar in the tuber is determined by the activity of the potato amylase system. Wright[18] has shown that both sucrose and reducing sugars increase during storage of potatoes at low temperatures; it is probable that the respirable substance is either sucrose itself or a substance closely linked with sucrose, possible the fructose half of the sucrose molecule, existing in the labile γ-fructose form.[116] Barker has also shown that the starch-sugar system is sensitive not only to the temperature of storage but also to its previous temperature history.[117]

The sensitivity of the sugar producing system can be reduced by a process of adaptation to intermediate lower temperatures and increased by prior exposure to higher temperatures. This has been confirmed by Denny and Thornton.[118] Storage at low temperatures apparently produces an enduring depression of the respiratory mechanism, which continues for long periods through subsequent high temperatures, and Barker[107] has suggested the accumulation of a "depressant" during cold storage, which is developed at higher temperatures. Once produced, the depression is irreversible. Thus the previous and current history of potatoes are of considerable importance *vis-à-vis* their sugar content.

Denny and Thornton[113] have determined the sugar content of the juice of the tuber before and after storage. Soon after harvesting, the juice contains no reducing sugar and 0·1 mg. to 6·3 mg. sucrose per ml. juice. After storage for various times at different temperatures, the juice contains up to 20 mg. reducing sugar and 30 mg. sucrose per ml. The changes in reducing sugar and sucrose are not parallel. When the potatoes are made into chips, the colour of the chips, due to caramelization, is determined by the concentration of reducing sugar only. A product of satisfactory colour is obtained using potatoes containing 3·0 mg. reducing sugar per ml. juice; a content of 5 mg. reducing sugar gives chips too dark in colour. The best results are obtained by storage at 70° C. The increase of sugar on storage is found to be a varietal characteristic but is not related to the environmental condition during growth. The presence of 2·5 per cent. to 4·9 per cent. carbon dioxide in the atmosphere caused a considerable decrease in the production of reducing sugar in potatoes stored at 5° C.[119]

Pectins

The pectic constituents of the potato have been studied but little. The values obtained for the pectin contents of the potato are summarized in Table XI.

TABLE XI

PECTIN CONTENT OF THE POTATO TUBER

Investigator or Source	Soluble pectin Per cent.	Insoluble pectin Per cent.	Total pectin Per cent.
Sweetman[24]	0·05–0·09	0·6–1·2	—
Langworthy[4]	—	—	0·2–0·4
*Freeman and Ritchie[120] ..	—	—	0·4–0·6
Conrad[121]	Nil	—	0·5
*Dastur and Agnihotri[122]	0·6	0·2	0·8
	0·07–0·11	0·3–0·5	0·6–0·8

* These workers reported their results as Ca pectate, which has been converted to pectin by using the Ca content of Ca pectate given by Hinton[123] (7·63 per cent. Ca).

Acids

McCance *et al.*[10] have reported a titratable acidity of 38 ml. of N/10 alkali per 100 g. peeled potatoes, whilst Sherman[124] gives a figure of 70 ml. The acidity of Armenian potatoes has recently been reported[35] to be 20 ml. to 49 ml.; volatile acidity 2·0 ml. to 17 ml. Robertson and Smith [125] found the *p*H values of immature potatoes to vary between 5·5 and 6·2, whilst those of mature tubers vary between 5·65 and 5·80. Ostanin[126], however, found the *p*H of the juice to be 5·75 to 6·56 and Ingold[127] has reported a value of 6·2.

The information regarding the actual acids present in the tuber is rather scanty and still partly conflicting. It is summarized in Table XII. Rather more definite results have been recently obtained by Curl and Nelson,[128] who worked up the juice expressed from 23 kg. of potatoes and identified citric, *l*-malic, isocitric and oxalic acids. Citric acid was the largest single component.

TABLE XII

ACIDS PRESENT IN THE POTATO TUBER

Acid identified	Source or investigator
Oxalic acid	Winton[22], Ingold[127], Curl and Nelson[128]
Citric acid	Guthrie[129], Ingold,[127] Hartmann and Hillig,[130] Curl and Nelson[128]
Isocitric acid	Curl and Nelson[128]
Malic acid*	Curl and Nelson,[128] Ingold[127]
Tartaric acid	Ingold[127]
†Succinic acid	Blyth[131]

* Reported to be absent by Hartmann and Hillig.[130]
† Reported to be absent by Ingold.[127]

TABLE XIII. MINERALS AND "TRACE" ELEMENTS PRESENT IN THE POTATO TUBER

Investigator or source	Ref.	Year	P mg./100 g.	Ca mg./100 g.	Mg mg./100 g.	Na mg./100 g.	K mg./100 g.	Fe mg./100 g.	S mg./100 g.	Cl mg./100 g.	Zn mg./100 g.	Br p.p.m.	Cu mg./100 g.	B p.p.m.	Si mg./100 g.	Mn mg./100 g.	F —	I p.p.m.	Li p.p.m.	As p.p.m.	Co p.p.m.	Ni p.p.m.	Mo p.p.m.	Al mg./100 g
Headden ..	15	1928	174*	66·9*	103*	54·8*	2289*	10·5*	75*	129*	—	—	—	—	—	2·6*	—	—	—	—	—	—	—	6·4*
		1928	178*	58·4*	93·5*	44·8*	2350*	10·0*	80*	144*	—	—	—	—	—	2·3*	—	—	—	—	—	—	—	8·9*
		1928	119	23·5	81·9	Nil	1811	5·3	54	45	—	—	—	—	—	Nil	—	—	—	—	—	—	—	0·2
		1928	241	103	144	320	2625	18·1	122	530	—	—	—	—	—	8·1	—	—	—	—	—	—	—	35·4
		1928	135	45·2	78·4	9·0	1811	4·8	43	66	—	—	—	—	—	0·6	—	—	—	—	—	—	—	2·9
		1928	228	88·3	130	332	2530	39·2	110	203	—	—	—	—	—	6·2	—	—	—	—	—	—	—	32·2
Bertrand ..	135	1925	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·07	0·26	—	—
Bertrand ..	136	1929	—	—	—	—	—	—	—	—	2·2	—	—	—	—	—	—	—	—	—	—	—	—	—
Orr and Leitch†	137	1929	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·12	—	—	—	—	—	—
		1929	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·05	—	—	—	—	—	—
McClendon ..	138	1929	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·33	—	—	—	—	—	—
Remington ..	139	1929	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·21	—	—	—	—	—	—
Richards ..	140	1930	—	—	—	—	—	—	—	—	—	—	—	—	—	1·2	—	—	—	—	—	—	—	—
		1930	—	—	—	—	—	—	—	—	—	—	—	—	—	0·75	—	—	—	—	—	—	—	—
		1930	—	—	—	—	—	—	—	—	—	—	—	—	—	0·47	—	—	—	—	—	—	—	—
Grendel† ..	141	1930	—	—	—	—	—	—	—	—	—	—	0·44	—	—	—	—	—	—	—	—	—	—	—
James	142	1931	—	—	—	—	2150	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Vincent	143	1931	—	18·6	45·9	—	1975	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		1931	—	22·9	47·1	—	1751	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Orr	144	1931	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·10	—	—	—	—	—	—
ter Meulen ..	145	1931	—	—	—	—	—	—	—	—	—	—	0·14	—	—	—	—	—	—	—	—	—	0·26	—
Kemmerer ..	146	1932	—	—	—	—	—	—	213	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Damiens	147	1932	—	—	—	—	—	—	—	475	—	8·5	—	—	—	—	—	—	—	—	—	—	—	—
Shirahama ..	148	1932	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3·87	—	—	—	—	—	—
Mayrhofer† ..	149	1932	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Not found	0·10	—	—	—	—	—	—
		1932	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·04	—	—	—	—	—	—
Schrader ..	19	1933	459	120	137	310	2475	—	261	805	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		1933	292*	66*	106*	84*	1962*	—	186*	356*	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		1933	202	44	68	34	1531	—	140	112	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Winton ..	22	1935	229	36·3	113	124	2048	18·5	109	—	1·74	—	1·0	—	—	1·9	—	0·08	—	0·35	—	—	—	7·6
		1935	—	—	—	—	—	9·9	—	—	—	—	0·4	—	—	8·5	—	—	—	—	—	—	—	4·2
		1935	—	—	—	—	—	3·7	—	—	—	—	2·0	—	—	0·2	—	—	—	—	—	—	—	—
		1935	—	—	—	—	—	3·0	—	—	—	—	2·83	—	—	0·6	—	—	—	—	—	—	—	—
Steudel	150	1935	430	—	—	—	—	—	247	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		1935	199	—	—	—	—	—	135	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
McClendon ..	152	1934	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·09	—	—	—	—	—	—
		1934	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·23	—	—	—	—	—	—
Holley	151	1935	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·05	—	—	—	—	—	—

TABLE XIII—*Continued.* MINERALS AND "TRACE" ELEMENTS PRESENT IN THE POTATO TUBER

Investigator or source	Ref.	Year	P mg./ 100 g.	Ca mg./ 100 g.	Mg mg./ 100 g.	Na mg./ 100 g.	K mg./ 100 g.	Fe mg./ 100 g.	S mg./ 100 g.	Cl mg./ 100 g.	Zn mg./ 100 g.	Br p.p.m.	Cu mg./ 100 g.	B p.p.m.	Si mg./ 100 g.	Mn mg./ 100 g.	F —	I p.p.m.	Li p.p.m.	As p.p.m.	Co p.p.m.	Ni p.p.m.	Mo p.p.m.	Al mg/ 100 g.
Nemec	164	1936	314	85	217	—	2825	—	191	—	—	—	—	—	17·3	51·1	—	—	—	—	—	—	—	—
		1936	239*	59*	150*	—	1966*	—	133*	—	—	—	—	—	11·2*	26·3*	—	—	—	—	—	—	—	—
		1936	251*	61*	100*	—	1906*	—	136*	—	—	—	—	—	10·3*	20·9*	—	—	—	—	—	—	—	—
		1936	152	35	78	—	1394	—	92	—	—	—	—	—	5·1	13·2	—	—	—	—	—	—	—	—
Mangold	25	1936	209	35	65	26·1	1479	—	122	117	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		1936	483	130	130	296	2262	—	270	709	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Breckpot	153	1936	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Trace	—	—	—	—	—
Heller	154	1936	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·21	—	—	—	—	—	—
Mottram	9	1937	175	33·5	—	—	—	3·26	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sherman†	155	1937	230	56·5	122	95·7	1980	4·33	152	174	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Bertrand	156	1937	605	—	—	—	—	—	423	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Mader and Mader	157	1937	—	—	—	—	—	71·5	—	—	—	—	2·3	—	—	—	—	—	—	—	—	—	—	—
Allen	158	1938	283	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Davidson†	159	1938	314	—	—	—	—	—	177	378	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Imp. Bureau†	28	1938	248	56·5	—	—	—	2·61	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Tottingham†	160	1939	130	10·0	—	—	—	6·0	—	—	—	—	0·06	4·5	—	—	—	—	—	—	—	—	—	—
		1939	420	71·4	—	—	—	28·0	—	—	—	—	0·15	8·6	—	—	—	—	—	—	—	—	—	—
		1939	350*	39·3*	—	—	—	13·3*	—	—	—	—	0·11*	6·4*	—	—	—	—	—	—	—	—	—	—
Titus	31	1939	283	94·3	—	—	—	—	—	—	—	—	—	—	—	1·42	—	—	—	—	—	—	—	—
Horner	161	1939	207	36·5	84·4	—	1992	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Fraps and Fudge	162	1939	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·39	—	—	—	—	—	—
McCance	10	1940	167	31·8	100	26·9	2347	3·10	143	325	—	—	0·62	—	—	—	—	—	—	—	—	—	—	—
Ford	163	1940	—	—	—	—	—	—	—	—	—	4·8	—	—	—	—	—	—	—	—	—	—	—	—
Brautlecht	36	1940	150	110	120	—	2200	—	90	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		1940	240	—	130	—	2600	—	240	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
McVicar	165	1941	—	—	—	—	—	—	—	—	—	—	—	5·5	—	—	—	—	—	—	—	—	—	—
		1941	—	—	—	—	—	—	—	—	—	—	—	9·5*	—	—	—	—	—	—	—	—	—	—
		1941	—	—	—	—	—	—	—	—	—	—	—	10·8*	—	—	—	—	—	—	—	—	—	—
		1941	—	—	—	—	—	—	—	—	—	—	—	13·9	—	—	—	—	—	—	—	—	—	—
Pfund & Nutting	166	1942	—	—	—	—	—	3·52	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Chaminade	169	1943	178	36	102	—	2470	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Oser *et al.*	181	1943	204	36·5	—	—	—	2·61	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cruess	168	1943	261	63	—	—	—	4·1	—	—	—	—	0·77	—	—	—	—	—	—	—	—	—	—	—
Leichsenring	170	1943	150	18·7	—	—	—	1·04	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		1943	381	40·4	—	—	—	2·65	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		1943	138	17·8	—	—	—	1·17	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		1943	359	63·8	—	—	—	2·65	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

* Average values. † Refers to analyses on peeled potatoes. All the results given in this table have been calculated on a dry basis.

Minerals and Trace Elements

There is a considerable body of literature dealing with the minerals and trace elements present in the potato tuber. The available data are given in Table XIII. Where necessary, the authors' results have been converted to those adopted here (mg. per 100 g. or parts per million, dry basis). These results have been summarized in Table XIV), which shows the extreme limits recorded for each element, together with narrower limits obtained by elimination of the more isolated values recorded.

Godden,[132] following Fearon,[133] has divided the elements occurring in animals and plants into six groups and this means of classification has been adopted here.

Group I. Invariable Primary Elements (H, C, N, O, P)

The only element to be discussed here is phosphorus ; the nitrogen compounds have already been considered. The extreme limits obtained for the phosphorus content of the tuber (dry basis) are 119 mg. to 605 mg. per 100 g.; the narrower limits are 150 mg. to 314 mg. McCance and Widdowson[10,134] have stated that about 80 per cent. of the phosphorus exists in an available (non-phytic) form and Yang and Dju[171] found that 85 per cent. was in a non-phytic form. Allen[158] fractionated the phosphorus compounds of the potato into fractions soluble and insoluble in 10 per cent. trichloracetic acid, of which the acid-soluble fraction contained both organic and inorganic phosphorus compounds. One of these has been identified as phytin and another as a hexosemonophosphate which closely resembled the Embden ester. The other fractions were not identified. According to Leichsenring and Donelson,[170] the phosphorus is more concentrated in the medullary layer than in the other zones.

Group II. Invariable Secondary Elements (Ca, Mg, K, Fe, S, Cl)

Except for iron, there is no recorded evidence as to the proportion of these elements present in a nutritionally available form. McCance and Widdowson[10,172] have found that 98 per cent. of the iron is present in an available form, a result confirmed by Pfund and Nutting[166] and by Smith and Otis.[173] Pfund and Nutting have also shown that the highest concentration of iron in the tuber is in the skin (18 mg. to 92 mg. per 100 g., average 56 mg.). According to Leichsenring and Donelson,[170], calcium and iron are more highly concentrated in the skin and the cortical layer. Woodman and Evans[12] have obtained similar results for calcium (cf. Table III).

Group III. Variable Secondary Elements (Zn, Ti, V, Br)

These elements may reach a relatively high concentration in certain species, where they are necessary for life, but their occurrence in other species is as yet doubtful.[132] Titanium and vanadium have not yet been identified in the potato tuber. According to Schreven,[174] zinc appears to be essential for the normal growth of the potato. The values recorded for the zinc and bromine contents of the tuber have been summarized in Table XIV.

Group IV. Invariable Micro-constituents (Cu, B, Si, Mn, F, I)

According to Godden,[132] these are believed to be present in all forms of life, but only in small quantities. They usually constitute less than 0·005 per cent. of tissue weight (in the potato tuber, 50 parts per million tissue weight or 200 p.p.m., dry basis). Of these, fluorine is apparently absent from potatoes. The values for the others are given in Table XIV.

TABLE XIV

MAXIMUM AND AVERAGE VARIATIONS OF THE MINERALS AND "TRACE ELEMENTS" PRESENT IN THE POTATO TUBER

(ALL RESULTS CALCULATED TO A DRY BASIS)

Group	Character	Element	Extreme limits	Narrower limits	Units used
I	Invariable primary elements	Phosphorus	119 – 605	150 – 314	mg./100 g.
II	Invariable secondary elements	Calcium	10 – 130	32 – 88	,,
		Magnesium	46 – 217	65 – 137	,,
		Sodium	Nil– 332	26 – 332	,,
		Potassium	1390 –2830	1810 –2600	,,
		Iron	1·0 – 71·5	2·6 – 10·5	,,
		Sulphur	43 – 423	109 – 213	,,
		Chlorine	45 – 805	112 – 530	,,
III	Variable secondary elements	Zinc	1·7 – 2·2	1·7 – 2·2	,,
		Bromine	4·8 – 8·5	4·8 – 8·5	p.p.m.
IV	Invariable micro-constituents	Copper	0·06– 2·83	0·4 – 1·0	mg./100 g.
		Boron	4·5 – 13·9	4·5 – 13·9	p.p.m.
		Silicon	5·1 – 17·3	5·1 – 17·3	mg./100 g.
		Manganese	Nil– 51·1	0·6 – 8·5	,,
		Fluorine	Not found	Not found	—
		Iodine	0·01– 3·9	0·02– 0·57	p.p.m.
V	Variable micro-constituents	Lithium	Trace	Trace	—
		Aluminium	0·2 – 35·4	2·9 – 8·9	mg./100 g.
		Arsenic	0·35	0·35	p.p.m.
		Molybdenum	0·26	0·26	,,
		Cobalt	0·07	0·07	,,
		Nickel	0·26	0·26	,,

Group V. Variable Micro-constituents

The elements falling in this class that have been detected in the potato tuber are lithium, aluminium, arsenic, molybdenum, cobalt and nickel.

Group VI. Contaminants (Ba, Hg, Th, Se, Au)

None of the elements so regarded have so far been identified in the potato.

Of the metallic elements present in the potato tuber, copper is definitely known to be associated with the enzyme polyphenoloxidase (see below). The role (if any) of the other metallic elements in the metabolism of the potato is at present not known.

VITAMINS

The literature dealing with the investigation of the vitamins present in the potato tuber and their changes on storage is already very considerable and can be only briefly summarized here. As is to be expected, the great majority of the papers have dealt with vitamin C, since the potato is an important source of this vitamin for human nutrition. The results obtained have been summarized by Fixsen and Roscoe,[175] and more recently (and in much greater detail) by Booher, Hartzler and Hewston.[176] In view of the existence of these summaries, no attempt will be made to present detailed summaries here.

Vitamin A.—Fixsen and Roscoe[175] mention in their first review that potato contains 28 μg. to 56 μg. carotene/100 g. but omit metnion of this from their more recent summary. Booher *et al.*[176] give a value of about 40 I.U. vitamin A/100 g. edible portion. Other values[31,38] vary between 49 and 88 I.U./100 g. Some workers have, however, stated that potatoes contain practically no carotene.[177,178]

Aneurine; *Vitamin* B_1 (*thiamin*).—Fixsen and Roscoe[175] give values ranging from 90 μg. to 180 μg. per 100 g., whilst Booher *et al.*[176] quote figures varying from 48 μg. to 186 μg. (average values 75 μg. to 110 μg.). More recent determinations[179,180] give results varying from 46 μg. to 179 μg. per 100 g. Pyke[178] has stated that the thiamin appeared to be uniformly distributed in the tuber, but Meiklejohn[180] has shown that the layer immediately below the skin contains less than the flesh. Freshly-dug tubers contain 77 μg. to 141 μg. per 100 g. The vitamin B_1 content rose quite considerably during growth. Losses on storage were mainly due to concentration of the vitamin in the sprouts.

Riboflavin; Vitamin B_2.—Fixsen and Roscoe[175] give values ranging from 7·5 μg. to 60 μg. per 100 g. whilst those quoted by Booher *et al.*[176] vary from 10 μg. to 55 μg. A more recent determination by Oser *et al.*[181] gave a value of 67 μg. per 100 g.

Nicotinic acid.—A recent table in *Nature*[39] quotes a figure of 1·4 mg. per 100 g., whilst a review by Bacharach[182] gives values of 1 mg. to 2 mg. and another review by MacVicar and Berryman[183] quotes values of 0·4 mg. to 2·0 mg. More recent determinations[181,184] have given values of 0·4 mg. to 0·8 mg. and 0·9 mg. per 100 g.

Pyridoxine; Vitamin B_6.—The recent table in *Nature*[39] gives a tentative value of 0·15 mg. per 100 g. Swaminathan[185] has reported this vitamin to be present in potatoes and Schneider *et al*[186] report a value of 0·4 mg. per 100 g.

Pantothenic acid.—Nature[39] quotes a tentative value of 0·3 mg. per 100 g., whilst Jukes[187] reports a value of 0·65 mg.

Biotin; Vitamin H.—Lampen, Bahler and Peterson[188] have found that potatoes contain 1·7 μg. biotin per 100 g. dry solids, all of which is present as free biotin.

Vitamin K.—According to Dam and Glavind,[189] potatoes contain less than 10 units vitamin K per g. dry solids.

Folic acid.—Nature[39] quotes a tentative value of 0·12 mg. per 100 g.

Vitamin P.—Bacharach and Coates[190] have obtained values of 25 to 40 provisional units per 100 g.

Vitamin D.—According to Titus,[31] this vitamin is absent from potatoes.

Vitamin E.—So far as is known, no investigations have been reported into the presence of this vitamin in potatoes.

Vitamin C.—The overall maximum variations in ascorbic acid content (irrespective of age, conditions of storage, etc.) are 3 mg. to 41 mg. per 100 g. according to Fixsen and Roscoe,[175] and 5 mg. to 45 mg. according to Booher, Hartzler and Hewston.[176] According to the latter tables, new potatoes contain 13 mg. to 45 mg. per 100 g., whilst old potatoes (3 months or more in age) contain 6 mg. to 13 mg. per 100 g. The results of more recent determinations[39,181,191,192,193,194,195,196,197,198,199] fall within these limits, with the exception of those obtained by Chappell,[199] who reports that old potatoes contain as little as 2 mg. to 4 mg. per 100 g. As these results show, it has now been clearly established that the ascorbic acid of potatoes decreases on storage. This decrease is very rapid at first and then gradually slows up until a constant value is reached.[192,195,200,201,202,203,204] In contrast to the marked loss of ascorbic acid in raw tubers on storage is the observation made by Aykroyd[205] that dried potato lost only 10 per cent. of its ascorbic acid content after 12 weeks' keeping at room temperature in an unsealed, closed tin. Possibly the ascorbic acid had been protected by the gelatinized starch against oxidation in air.

The total antiscorbutic activity of potatoes is due to the sum of the ascorbic and dehydroascorbic acids present, but there is as yet no general agreement whether dehydroascorbic acid is always present or not. Some workers have reported that this acid is either completely absent or is present only in small amounts,[193,199,202,206,207] whilst others have reported that it forms a substantial part of the total vitamin C of potatoes.[196,197,208,209] In view of these observations the results obtained by Smith and Gillies[201] are of particular interest. They showed that, as the content of ascorbic acid fell on storage from 19·7 mg. to 6·6 mg. per 100 g., that of dehydroascorbic acid rose from 0·3 mg. per 100 g. until it reached a constant value of 2·1 mg. to 2·5 mg. This result led to the suggestion that, when potatoes are stored, the "reduced" ascorbic acid is first oxidized to the dehydroascorbic acid and this is then further irreversibly oxidized. These changes have already been observed during the oxidation of ascorbic acid by chemical means.[210] It has been reported by Rosenfeld[222] that at *p*H 7 in the presence of phosphate or cyanide, dehydroascorbic acid is decomposed with the production of oxalic acid. This reaction is irreversible and non-oxidative. There appears to be little doubt that storage is the most important single factor in determining the vitamin C content of potatoes.

The distribution of ascorbic and dehydroascorbic acids through the potato tuber has been the subject of a number of studies. It appears that the peel contains less ascorbic acid than the peeled tissue,[192,196,206,207,208,211] especially in new potatoes, the difference becoming smaller as storage proceeds.[192,199] Wolf[196] and Fujita and Ebihara[208] have, however, reported that the peel contains more dehydroascorbic acid than the peeled tissue, so that the total vitamin C content of the peel may be higher than that of the flesh. Kroner and Volksen[206] have shown that this conclusion is true only in a minority of cases; on the whole, the total vitamin C of the peel was lower than that of the peeled tissue. They suggest that the distribution may depend on the variety and the time and temperature of storage. On the other hand, Lauersen and Orth[209] report equal contents of ascorbic and dehydroascorbic acids in the outer and inner layers of the tuber, and state that the cork skin itself contains no ascorbic acid at all. Ascorbic acid itself has been reported by a number of workers to be unevenly distributed in the tuber,[201,202,212] but Esselen, Lyons and Fellers[207] report even distribution.

The ascorbic acid content of potatoes varies greatly from variety to variety[191,192,212] and even from tuber to tuber within the same variety,[200,202,207] (especially in new potatoes). According to Smith and Gillies,[201] variety has some influence on the ascorbic acid content and especially on its disappearance during storage. They also report that the ascorbic acid passes from the sprouting tuber to the sprout. The greater vitamin C content of the sprouts has received further confirmation recently.[213] Olliver has shown[214] that the ascorbic acid content of potatoes remains constant throughout growth; immature tubers (weighing about 1 g.) and mature tubers (weighing up to 250 g.) had much the same ascorbic acid contents.

ENZYMES

A considerable but rather diffuse literature is available about the enzyme systems present in the potato tuber: it is summarized in Table XV.

Further work is clearly required to establish more definitely the presence of enzymes reported at a time when the available methods were not sufficiently specific. It can be said to-day that the presence of the following enzymes is now established:—polyphenoloxidase, tyrosinase, peroxidase, amylase and phosphorylase. The properties and effects of these and a few other enzymes are briefly discussed below.

(*a*) *Polyphenoloxidase*

According to Sumner and Somers[233] and to Baker and Nelson[221] "polyphenoloxidase" and "tyrosinase" are one and the same enzyme. It has also been called "phenoloxidase," "potato oxidase," "catechol oxidase" and "polyphenolase." Richter[229] and Kubowitz[225] have prepared polyphenoloxidase from potatoes; the enzyme is a copper-containing oxidase, with a copper content of 0·2 per cent. Removal of the copper inactivates the enzyme, which can be fully reactivated by addition of copper ions. The polyphenoloxidase has been stated[257] to oxidize a catechol derivative present in potatoes to a quinone, the latter giving dark-coloured products with proteins and amino-acids. The activity of the enzyme is increased by mechanical injury of the tuber, perhaps because the enzyme and the substrate are separated from one another in the undamaged tuber and only come into contact when it is damaged.[257] This may explain why damaged potatoes give dark colours whilst undamaged

TABLE XV

THE ENZYMES OF THE POTATO TUBER

Enzyme	*Reported by*	
Tyrosinase	Bechhold and Erbe[215] Kawasaki[217] Robertson[219] Winton[22] Lichtman and Sobotka[223]	Gould[216] Lauder and Robertson[218] Smith and Paterson[220] Baker and Nelson[221] Nobutani[224]
Polyphenoloxidase	Kubowitz[225] Wieland[226] Boswell and Whiting[228] Richter[229]	Bechhold and Erbe[215] Wachholder[227] Winton[22]
Peroxidase	Tonekha[230] Wachholder[227]	Topecha[231] Miller[232]
Laccase	Sumner and Somers[233]	
Catalase	Winton[22] Bunzell and Kenyon[234]	Topecha[231]
Aldehydrase	Winton[22]	
Oxidase	Winton[22] Donatelli[236]	Ito[235]
Ascorbic acid oxidase	Stone[237]	Johnson and Zilva[238]
Dehydrogenase	Topecha[231] Wartenberg[239]	Boswell and Whiting[228]
Amylase	Winton[22] Hanes and Barker[111] Doby and Burger[244] Borchardt and Pringsheim[245]	Haehn and Schweigert[240] Denny[241,242,243] Bois and Savary[108] McGuire and Falk[245a]
Sistoamylase	Gretshushnikov[246]	Sukhorukov[247]
Amylosynthease	Minagawa[248]	
Sucrase	Bois and Savary[108]	McGuire and Falk[245a]
Zymohexase	Allen[158]	
Phosphorylase	Hanes[249] Hassid and McCready[251] Meyer and de Traz[253]	Green and Stumpf[250] Hanes and Maskell[252]
Phosphatase	Guthrie[254] Ignatiev[256]	Pfankuch[255]
Erepsin	Miller[232]	
Pectase	Sumner and Somers[233]	

potatoes do not. Boswell and Whiting[228] have shown that the system polyphenoloxidase–phenolic substrate–dehydrase is responsible for the major part of the respiratory mechanism of the tuber. This has been confirmed more recently by Baker and Nelson.[221]

The most sensitive reagent for this oxidase has been found to be a pyrocatechol–glycine mixture[215]; the activity of the enzyme is inhibited by carbon monoxide and by cyanide.[258] According to Wieland[226] the oxidase activity of the skin is greater than that of the flesh. The oxidation of mono- and dihydric phenols by polyphenoloxidase has been studied by Richter.[229]

(*b*) *Tyrosinase*

Although modern opinion regards this enzyme as being identical with polyphenoloxidase, it will be discussed separately here since much of the work concerned deals with its effect on tyrosine or related substances. According to Baker and Nelson,[221] the name "tyrosinase" is preferable since the enzyme will oxidize monohydric as well as polyphydric phenols. Potato tyrosinase has been stated to be inactivated at the same temperature as animal tyrosinase,[216] to have an optimum temperature of 35° to 40° C. and an optimum *p*H of 7 to 9.[217] Raper[259] has shown that the oxidation of tyrosine by tyrosinase leads finally to the formation of the dark pigment melanin, and Nutting[260] demonstrated recently that the black pigment obtained when raw potatoes or raw potato juice are allowed to auto-oxidase in air is identical with the melanin produced when the purified tyrosinase is allowed to react with tyrosine. The two pigments gave practically identical absorption spectra in the ulta-violet and had similar chemical properties. According to Scott[261] bruised potatoes turn black through the same mechanism that causes cut surfaces to blacken; blackening occurred in any part of the tuber "killed" by means that did not inactivate the enzymes present (e.g., age, frost, bruising). Blackening may be connected with the labile blue compound found in potato juice by Roach.[262] More tyrosinase has been reported to be present in the outer than in the inner layers of the tuber.[215]

McIntosh[263] and later Lauder and Robertson[218] have used the reaction between potato tyrosinase and *p*-cresol to distinguish between different varieties of potato. The reaction is uninfluenced by environment, soil reaction, seasonal variations or storage but is influenced by the maturity of the potatoes, by the variety and by freedom from disease.[219] Further tests showed that many but not all varieties could be thus identified.[220] Tyrosinase activity has been reported to be higher in diseased than in normal tubers.[230] Lichtman and Sobotka[223] have described a method for the preparation of the tyrosinase in a dry form. They also state that young potatoes yield a more active enzyme than old potatoes.

(*c*) *Peroxidase*

This enzyme is stated by Sumner and Somers[233] to occur in nearly all plant cells and Miller[232] describes it as being abundant in the potato tuber. Peroxidase catalyses the oxidation of many phenols and aromatic amines in the presence of hydrogen peroxide. Peroxidase activity has been reported to be higher in diseased than in normal tubers by Tonekha[230] and by Topecha.[231] Wachholder[227] has reported the presence of peroxidase in normal tubers.

(*d*) *Catalase*

According to Topecha,[231] catalase activity is raised in diseased tubers.

(*e*) *Dehydrogenase*

According to one author,[231] the most characteristic difference between normal and diseased potatoes lies in their dehydrogenase content, the dehydrogenase activity being measured as the rate of decolorization of methylene blue by the potato juice under anaerobic conditions. According to Boswell and Whiting,[228] this enzyme is also concerned with the respiratory mechanism of the potato tuber.

(*f*) *Ascorbic Acid Oxidase*

According to Stone,[237] this enzyme is present in the tuber, but Johnson and Zilva[238] showed that, although the ascorbic acid does undergo oxidation, this is due to quinones produced by the oxidation of mono- and polyhydric-phenols by the oxidases present. The specific ascorbic acid oxidase is thus not present.

(*g*) *Amylase*

It has already been mentioned (see under "Sugars") that sugar is formed in the tuber through the agency of the amylase present.[111] Amylase activity has been found to increase on storage.[244] According to Haehn and Schweigert,[240] the amylase present in the juice of the tuber is inactivated by dialysis but can be reactivated by the addition of potassium chloride or sodium chloride. The amylolytic activity of the juice is considerably increased by addition of neutral salts (NaCl, KCl, $CaCl_2$, NaF, $MgCl_2$) or of amino-acids (glycine, alanine and leucine).

Borchardt and Pringsheim[245] have concluded that the potato amylase is intermediate in character between malt amylase (a mixture of α- and β-amylases) and takadiastase (mainly α-amylase). The earlier work of Haehn and Schweigert[240] also indicates that potato amylase has some of the properties of an α-amylase, but this conclusion needs re-investigation by more accurate methods (e.g., those of Hanes and Catte[264]).

(*h*) *Phosphorylase*

Hanes[249] showed that the potato tuber contains a phosphorylase that will convert glucose-1-phosphate into starch and vice versa. The starch obtained is similar in chemical constitution and in physical properties to the "straight-chained" fraction of potato starch (see under "Starch"). On the other hand, both the "straight-chained" and the "branched-chained" starch macromolecules are converted to glucose-1-phosphate by phosphorylase. A number of workers have since confirmed Hanes' results.[250,251,252,253]

(*i*) *The Blackening of Boiled Potatoes*

The blackening of the tissue of boiled potatoes has been the subject of a considerable number of investigations from various points of view. It will be discussed here, since the evidence shows that it may be connected with the oxidizing enzymes present in the potato. The evidence available at present is summarized below:

(*a*) Nutting and Pfund[265] have shown that the blackening of boiled potatoes does not occur during the actual boiling process but takes place when the boiled potatoes are allowed to stand in air. When boiled potatoes are allowed to stand in nitrogen, blackening does not take place. This has been confirmed by Robison,[88] who found that blackening does not occur until air has been admitted. (It is of interest that the so-called "eye-blackening" which occurs only in small areas round the "eyes" takes place during boiling and is not noticeably intensified during subsequent exposure to air. Nutting and Pfund have suggested that this blackening is due to melanin formation.[265])

(*b*) Tottingham *et al.*[266] have suggested that blackening after boiling is due to the formation of melanin through the action of the enzyme tyrosinase on tyrosine as with raw tubers exposed to air (see above). They showed that potatoes which blackened after boiling contained more tyrosine and had a greater tyrosinase activity than normal potatoes. The former also contained more nitrogen and more free amino-acids than the latter. In addition, the abnormal potatoes had a higher proteolytic activity.[84] Cooking was thought to break open the cells of the tissue and allow atmospheric oxygen to enter more freely.[267] However, Robison[88] and also Nash[268] found no correlation between the tendency to blacken after boiling and the tyrosine content and Robison found no correlation between the tendency to blacken and the tyrosinase activity.

(*c*) Nutting[260] has shown that the dark pigment extracted from boiled potatoes did not have the same properties as the melanin prepared either from raw potatoes or from tyrosine by the action of tyrosinase, but was related to the flavones. The ultra-violet absorption spectrum of the dark pigment from boiled potatoes was different from that of true melanin but was similar to that of the yellow pigment extracted from both blackened and non-blackened tubers. This conclusion is supported by the independent observation[88] that the pigment of boiled potatoes disappeared at *p*H 3, at which melanin is stable.

(*d*) Smith, Nash and Dittman,[269] Nash[268] and Smith and Nash[40] have observed that the temperature at which tubers mature is related to the occurrence of blackening. Tubers maturing at low temperatures (50° C. to 60° F.) were more likely to blacken than those maturing at higher temperatures (70° C. to 80° F.). After tubers known to blacken severely had been exposed to a temperature of 100° F. for 3 to 4 days, they no longer blackened after boiling. These authors quote evidence that shows that there is more oxygen in potato tissue at 11° C. than at 22° C., and that higher temperatures reduce the oxidation-reduction potential,[271] thus providing an explanation for the authors' results. Against this, Clagett and Tottingham[197] have found that there was no relation between the tendency to blacken and either the ascorbic acid content or the total reducing power of the raw tubers. Nash and Smith[32] have, however, obtained supporting evidence for the view that blackening is related to the conditions under which the tubers mature. They tried the effect of periodic shading of the plants during the time of maturation, so that the light intensity on the shaded plants approximated to that obtaining on a cloudy day. It was found that tubers from shaded plants had less starch, less protein nitrogen, more soluble nitrogen, more α-amino-nitrogen, more tyrosine and a greater phenol content. Tubers from shaded plants to which excess of nitrogenous fertilizer had been added showed much more marked blackening than those from shaded plants which had not received the extra nitrogen.

(*e*) Tottingham and Clagett,[272] in a preliminary note, have stated that the polyphenoloxidase activity of tubers tending to blacken is greater than that of normal tubers. Their results are stated to show that a primary cause of the blackening of boiled potatoes is a departure from normal respiratory relations after harvesting. This conclusion is supported by the observation that the compound causing discoloration after boiling is related to catechol,[197] which is easily oxidized by polyphenoloxidase.

(*f*) Cowie[273] has found that blackening is caused by an ill-balanced supply of nutrients to the soil (high N content combined with low K content). Under these conditions, amino-acids are likely to increase relatively to the protein. This view is supported by the results obtained by Nash and Smith.[32]

(*g*) Tonekha[230] has suggested that the blackening is due to peroxidase activity.

The evidence so far obtained shows that the blackening of boiled potatoes is due to an oxidation process, the exact nature of which is still to be determined. Nutting and Pfund[265] have questioned whether the oxidation can be enzymic in character, since boiling would have inactivated the enzymes present. This, however, is not conclusive; the gelatinized starch may protect the enzymes from inactivitation by heat.

It is unfortunate that a very comprehensive study of the factors governing "blackening," undertaken by Prof. Blackman for the Potato Marketing Board, was brought to a standstill by the outbreak of war. Our laboratory collaborated in this study by undertaking the determination of the colour of samples of potatoes from all parts of the country, grown under known conditions on soils of known characteristics. Over 1500 samples had been examined.

MINOR CONSTITUENTS OF THE POTATO

Reducing Substances

Evidence has been obtained that ascorbic acid is not the only reducing substance present in the tuber. Thus *glutathione* is present, the juice containing 2 mg. to 5 mg. per 100 g.[274] Pett[203] has observed that the glutathione and the ascorbic acid of the potato undergo parallel changes on storage. At first both increase and then both fall together. Clagett and Tottingham[197] found that the total reducing power of the tissue was about double that due to the ascorbic acid alone. Trout and Kidd[275] have recorded that potatoes had an equilibrium quantity of 0·7 mg. *acetaldehyde* per 100 g. tissue in air and 1·2 mg. in nitrogen. Trumpener[276] has reported that the oxidation-reduction potential of the potato is connected with its "state of health" and has used this to develop a rough and ready test in which the potato is coloured by an inserted piece of copper foil. Healthy and diseased tubers were coloured differently.

Pigments

Winton[22] refers to the presence of porphyrin in the tuber and flavones are known to be present.[260,263,277] According to McIntosh,[263] the intense yellow colour given by flavones with alkali can be used to some extent for distinguishing between different varieties of potatoes. This test is unaffected by virus diseases, maturity or by the ferilizers used. Violet-coloured potatoes have been found to contains two anthocyanins.[278]

Phenols

Clagett and Tottingham[197] found that the whole potato contains 5 mg. to 6 mg. catechol per 100 g., the peel 9 mg. to 14 mg. and the peeled tissue 3 mg. to 7 mg. The catechol was concentrated in the peel and the underlying tissues. Nash and Smith[32] found that normal potatoes contained 56 mg. total phenols per 100 g. fresh weight. The content of total phenols was increased by periodic shading of the plants whilst the tubers were maturing.

Fluorescent Substances

Odehnal[279] has reported that normal tubers usually give either a typical dark greyish-green or a yellow fluorescence when their cut surfaces are examined in ultra-violet light. The fluorescence is retained when the tubers are heated in boiling water but disappears when they are kept in formalin. Weakened tubers show a typical blue fluorescence, whilst frozen or diseased tubers show this only in certain areas. The author concludes that these properties can be used for differentiating between healthy tubers suitable for seed purposes and unsuitable, unhealthy, weakened tubers.

Note.—Unless stated to the contrary, all the figures quoted in this chapter are given on the basis of wet tuber weight. Where other bases have been used, or the authors' data have been insufficient, the following average figures have been taken to convert the results recorded in the literature to those given here:

Dry total solids	23·0 per cent.
Ash	0·96 ,,
"Protein" ($N \times 6{\cdot}25$) ..	2·0 ,,
Edible material	86 per cent. of the whole tuber.

Factors Affecting the Composition of the Potato

Winton[22] has stated that the composition of potatoes is influenced by locality, seasonal variations, temperature, the degree of maturity of the potato, the method of culture and the fertilizers employed. Sweetman[24] has also discussed this question and to-day there is a considerable, but rather indecisive, mass of data, which can only be summarized briefly. Few of the investigators have submitted their data to statistical analysis, although the problem obviously calls for such a method of approach to determine whether an observed difference is due to the variation of a particular factor. It has already been mentioned that Goldthwaite's extensive investigation[1] showed that no two tubers, whether of the same variety or from the same "hill," were identical in composition. To-day, there is a good deal of evidence that the composition of potatoes is less affected by variety than by the environmental conditions under which they grow.[280]

The influence of variety and also of storage on the different constituents of the potato has already been discussed under each particular constituent and only the effects of fertilizers and of environmental conditions will be dealt with here.

Too much potash fertilizers will depress the starch, dry solids and nitrogen contents[281]; nitrogen fertilizers increased the nitrogen and potassium content and lowered the phosphorus content.[282] The presence of excess nitrate produces watery tubers of poor flavour in addition to the other effects produced by nitrogenous fertilizers.[15] The efficiency of phosphate fertilizers may be affected by the quantity of calcium present.[24] However, Mangold[25] has claimed that the use of artificial fertilizers did not affect the proportions of the constituents of the potato. Increasing the magnesium content has been claimed to have increased the immunity of the tuber to wart disease.[283]

Potatoes grown under Arctic conditions have been reported to have a much lower starch content but a higher sugar content than normal potatoes.[284] This has been attributed to increased amylase action.

According to Lyons and Fellers,[285] and Esselen, Lyons and

Fellers,[207] the vitamin C content of potatoes depends more on variety than on environmental conditions, but Wachholder and Nehring[198] have concluded that the nature of the soil has a greater influence than either the variety or the fertilizer used. Son Westas[191] has confirmed that the vitamin C content is affected by the nature of the soil but not by the fertilizer used. Scheunert *et al.*[194,195] have, however, found that the nature of the soil had no effect, and Illyuviev and Ulanova[302] report that the use of nitrogen and potash fertilizers increases the vitamin C content.

COOKING CHANGES

It is perhaps well to consider those characters of a cooked potato that count in judging quality (cf. Salaman and Brandreth).[286] A steamed or boiled potato should have a clean characteristic flavour that is neither stale nor earthy. The colour should be uniform and creamy without any darker patches. In consistency it should be "floury" or "mealy" and without lumps; it should not be of a "glutinous" nature. A chip potato should have sufficient potato flavour to taste above the flavour of the oil. In colour it should be golden brown. The chip should break cleanly and be "floury" in character.

Langworthy[4] has suggested that potatoes can be graded into three classes:—"Mealy," "soggy" and a class intermediate between these two—"Waxy."

The changes that take place in the potato tuber on cooking can be divided into two groups—(*a*) losses in various constituents, some of which are leached out by the cooking water and others destroyed by the heat treatment, and (*b*) physico-chemical changes both in the constituents themselves and in their relation to one another. These two aspects are considered separately below.

The literature dealing with the cooking of potatoes is considerable, but little of it is fundamental; the earlier work has been adequately summarized by Sweetman[24] in 1946, and by Rathsack[8] in German in 1935.

Losses during Cooking

These will be considered here under two separate headings—(*a*) losses in the major constituents and in minerals, and (*b*) losses in vitamins.

(*a*) *Losses in Major Constituents and Minerals.*

Analyses of potatoes before and after boiling[9,10,34] show that boiled potatoes contain slightly more water, and slightly less starch, total nitrogen and sugar than raw, and that a part of the mineral content has been lost.[9,10]

McCance, Widdowson and Shackleton[287] have carried out an extensive investigation into the losses of the nutritive constituents of many vegetables on cooking. They investigated the variation of the losses of minerals, nitrogenous bodies, titratable acidity and starch from potatoes both with the time of cooking and the method of cooking and their report should be consulted for details. They found that the losses increase very considerably with increasing time of boiling but that the variation of the ratio of water to potatoes does not have much effect. No losses (even of soluble salts) occur until the skins of the potatoes have burst. Potatoes boiled in their skins lose far less nutritive matter than peeled potatoes under the same conditions. Similar results have been obtained by earlier investigators[4,8,22,24]; these results are summarized in Table XVI. Soaking before boiling increases the losses very considerably.[24,28]

TABLE XVI

LOSSES OF CONSTITUENTS ON COOKING POTATOES

Investigator or source	Method of cooking	Percentage loss of				
		Dry solids	Carbo-hydrate	Total N	Ash	
		Per cent.	Per cent.	Per cent.	Per cent.	
Langworthy[4]	Direct into boiling water	—	3	8	18	Peeled potatoes
Langworthy[4]	Into cold water, then boiled	—	3	16	18	
Winton[22]	Direct into boiling water	3·4–4	2·8	8–10	17–18	
Winton[22]	Into cold water, then boiled	3·1–3·7	2·5	8–16	17–18	
Sweetman[24]	—	4	2·8	10	17	
Langworthy[4]	—	—	Nil	1	3	Unpeeled potatoes
Sweetman[24]	—	0·3	0·1	1	1·2	
Winton[22]	Direct into boiling water	0·3–0·4	0·1	1	1·2–3·3	
Winton[22]	Into cold water, then boiled	0·3–0·4	0·2	0·6–1	1·9–3·4	

As would be expected, losses increases as the size of the potato pieces being boiled decreases. Boiling in salt water does not affect the losses to any significant degree. Steaming causes smaller losses than boiling.[8,22,24] Baking, frying and roasting cause only very small losses.[4,24,287] Adam and Horner[288] have described the losses in sugars, minerals and proteins on blanching potatoes in water at 100° C. According to Pfund and Nutting[166] the losses in iron content on boiling are slightly greater for peeled than for unpeeled potatoes. More recently, Oser *et al.*[181] have obtained figures for the loss of iron, calcium and phosphorus on boiling potatoes in large and small quantities of water. Boiling in a small quantity of water extracted ess iron and phosphorus but did not affect the loss of calcium.

(*b*) *Losses in Vitamins.*

A considerable number of investigations have been made into the behaviour of the vitamins of the potato on cooking by various methods, most of them concerned with the ascorbic acid content. As this subject has been dealt with in detail in another part of the present volume,* it will not be discussed here. The relevant literature has also been summarized by Booher, Hartzler and Hewston,[176] and by Olliver.[200] The effects of the usual household methods of cooking potatoes on the loss of the ascorbic acid content have been investigated by Esselen, Lyons and Fellers.[207]

Physico-chemical Changes during Cooking

The early work on the physico-chemical changes that take place on cooking potatoes have been extensively discussed by Sweetman.[289] These may be summarized as follows.

Cooking causes mechanical disintegration of tuber tissues as the outcome of cell separation (the cells being left intact), accompanied by partial gelatinization of the starch, degradation of the pectins, coagulation of the protein and an increase in the digestibility of the cellulose. In addition, baking and frying caramelize the sugar present.

Personius and Sharp[290] have followed the changes in the ease of separation of the cells and of the weakening of their cementing material by tensile strength determinations. They found no relationship between the tensile strength and the size of the cells, the thickness of the cell-walls, the quantity of starch in the cells, the size of the starch granules, the texture, the variety of the potato or the storage conditions. There was no reduction in tensile strength of potatoes at 50° C. but above this temperature the rate of loss of tensile strength increased with rising temperature. The tensile strength was lower the higher the temperature. Definite weakening took place below the temperature at which the starch gelatinized, and it was therefore concluded that cell separation and starch gelatinization were independent. This conclusion was later confirmed by the same authors,[291] who transformed raw into "cooked" potatoes by successive treatments first with a starch gelatinizing agent (e.g., 40 per cent. chloral hydrate, 2N sodium salicylate or ammonium thiocyanate), and then by a 0·5 per cent. solution of ammonium oxalate to soften the tissues. Separately these reagents did not cause the potato to become "cooked," but used in succession they did so. Personius and Sharp concluded therefore that two fundamental changes were necessary to convert raw potato tissue into cooked tissue: (*a*) gelatinization of the starch and (*b*) a marked decrease in the cell adhesion of the tissue. It is interesting, however, that in these experiments, potatoes that gave "soggy" cooked potatoes when cooked in the normal manner still gave a "soggy" product when treated as described above; "mealy" potatoes still gave a "mealy" product. This led Personius and Sharp to the further conclusion that the texture of the potato is controlled by a separate factor. These results indicate how it is possible to prepare a dried "mashed potato" which on reconstruction with boiling water will yield a normal mashed potato. This has been achieved in a recent patent,[292] which describes how the potatoes are first boiled in a weak solution of lime or sodium carbonate and then dried. This treatment allows the starch to be gelatinized whilst the cell structure is preserved intact.

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* Olliver, *pp*.127-153.

The Texture and "Cooking Quality" of Potatoes

The texture and "cooking quality" of the tuber have been the subject of a number of investigations. Sweetman[24] has pointed out that there is a positive correlation between the "mealiness" of a cooked potato and the starch content of the raw potato; the later workers[32,293,294,295] have reported a similar correlation between the specific gravity of raw potatoes (which depends on the starch content) and their "mealiness"; the better the cooking quality or "mealiness," the higher the specific gravity and the starch content. The texture of potato tubers has been found to be influenced by environmental conditions, cultural practices and storage conditions.[24] Nash and Smith[32] have shown that tubers grown in the absence of sufficient sunlight are less mealy than those grown in the presence of more sunlight ; this was achieved by shading the plants during the period of maturation of the tubers. Low storage temperatures diminish mealiness and relatively high-cooking temperatures and escape of water from the cooked product increase it.[24] Sweetman[24] has suggested that mealiness may depend on the degradation and weakening of the pectin present in the cell-walls of the raw tissue, but Barmore[296] found that potatoes of equal starch contents but different degrees of mealiness have pectin contents tha did not correlate with mealiness. His results were not all satisfactory and this question must remain open. It should be pointed out, however, that it is not only the overall pectin content that may be important, but also its strength (i.e., its mean molecular weight, since in pectin the two are directly related).[297] It would be of interest to have this investigated.

It is also possible that the texture is controlled not only by the starch but also by either the total bound water or the bound water attached to the starch. Dumanski[42] has shown that the quantity of bound water increases almost threefold on cooking potatoes (0·57 g. to 1·51 g. bound water per g. dry solids) and it is possible that it is this increase that controls the resulting texture. The relation between bound water and texture has, however, not yet been investigated, although Stainken[298] has shown that a high water absorption on cooking can be correlated with a high degree of "mealiness" and a low water absorption or a loss in weight with "sogginess." This has been confirmed by Nash and Smith.[32]

Freeman[299] has made the interesting observation that "mealy" potatoes behave quite differently from "waxy" potatoes on baking them and subsequently drying slices of the baked potatoes. The dried mealy tissue is white and very porous whilst the dried waxy tissue turned into a dense, vitreous, horny sheet of a light tan colour. By this means, Freeman was able to prepare permanent standards from mealy and waxy potatoes, so that the textures of different batches of baked potatoes could be compared with some accuracy. The differences observed are due to the fact that cell separation after baking (or boiling) is much greater in mealy than in waxy potatoes.[24,291] In a later paper, Freeman[294] confirmed this by determining the porosity of the dried slices ; the greater the porosity of the dried tissue, the more mealy the baked potato. Freeman also showed that the water content of the tubers is a fairly reliable index of the texture of the baked tissue, and that there is a high degree of correlation between the specific gravity and the moisture content. This is not surprising since the water and the starch together make up most of the tuber (see under "Major Constituents"). Freeman concludes that the texture of baked potatoes is governed by the moisture content and the degree of cell separation. These factors may or may not be independent.

Rathsack[8] introduced two new methods for determining cooking quality in potatoes; he used a "disintegration index" Z ("Zerkochungsgrad") to give the degree to which the tubers disintegrate on cooking under standard conditions and a "texture index" S ("Schnittfestigkeit") given by the time taken by a fine wire to cut the tuber under standard conditions. Z is given by the expression.

$$[(a \times o) + (b \times 1) + (c \times 2) + (d \times 3)] = 3Z$$

where a = per cent. of tubers still whole after boiling,
,, b = ,, ,, ,, torn after boiling,
,, c = ,, ,, ,, split open after boiling,
,, d = ,, ,, ,, disintegrated after boiling.

This equation for Z is applicable only when a, b, c and d vary in a continuous fashion.

Z was found to be independent of the starch and protein contents and also of the starch : protein ratio, whereas S was positively related to the starch content (in agreement with the results of other workers on the factors governing texture ; see above). Z decreased with time of storage, a change that could be accelerated by placing the tubers in air at 35° C. Rathsack suggested that Z is connected with the swelling power and its decrease on storage is attributed to loss of swelling power. The following tests were used to determine whether potatoes were completely cooked :—(*a*) taste and feel in the mouth, (*b*) penetrometer tests, and (*c*) loss of weight in cooking. Of these tests the first was the most diagnostic, although all the three could be used to determine the optimum cooking time.

Salaman and Brandreth[286] have concluded that the influence of the soil on potato quality lay in its effect on the consistency of boiled potatoes, but flavour was little affected.

The Colour of Cooked Potatoes

The colour of cooked potatoes has been the subject of but few investigations. Sweetman[24] has divided the colour changes that may take place on cooking into three classes :

(*a*) The action of alkalis or metals on the flavones present in potatoes. The colours produced include various tints of green, yellow and brown.

(*b*) The caramelization of the sugars present in potatoes. It is unlikely that this change occurs in boiled potatoes but it certainly occurs in baked and fried ones. The extent of the browning was first shown to depend on the quantity of sugars present,[300] but more recently Denny and Thornton[113] have concluded that only reducing sugars are connected with the caramelization, the sucrose having no effect. The subject has already been fully discussed in the section dealing with the sugars of the potato.

(*c*) Blackening of the cooked flesh on exposure to air. Although there has been some definite progress in our knowledge of the causes of this blackening, much still remains to be done before it is fully understood. The available knowledge has already been discussed in the section dealing with the enzymes of the potato. The difficulty of judging the colour of cooked potatoes has necessitated the development of an optical method of determination; this was used by us in our work for the Potato Marketing Board.[301]

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CHAPTER VIII

THE NUTRITIVE VALUE OF THE POTATO

By Harriette Chick

The potato takes an important place in any dietary as an energy-bearing food and, since it can be satisfactorily grown in this country, it is of special importance at the present time as a partial substitute for bread and those cereals which to a large extent need to be imported. In Table I are summarized average values for its content of nutritive elements, compared with those of bread, and it will be seen that the calorie and carbohydrate content, reckoned on a dry weight basis, are of about the same order as those of white or wholemeal bread. The protein is lower in amount, but, as will be seen below, its *quality* is good. Of minerals the potassium is higher, the calcium lower, and the content of available phosphorus and iron about equal in amount to that of white bread, though lower than that of wholemeal.

Digestibility.—Many human experiments, among the most notable of which are those of Rubner, have shown that on a potato diet about 5 per cent. of the total calories remained undigested; the loss in nitrogen was greater and varied from 15 per cent. to 30 per cent.[1] In experiments made by Rubner with the finest white flour, there was a loss of only 6 per cent. of the ingested nitrogen in the faeces, but with "whole" meal (95 per cent. extraction in the milling) the loss was about 30 per cent., similar to that suffered with the nitrogen of the potato.[2] Abderhalden and his colleagues,[3] in observations on the same human subject, found an average loss of 18 per cent. of the ingested nitrogen from a potato diet, and of 19 per cent. from one of white bread. In recent work by Macrae *et al.*[4] the losses from diets of white and wholemeal (100 per cent. extraction flour) breads were respectively 9 per cent. and 15 per cent.

Protein and other nitrogenous constituents.—The amount of nitrogenous substances varies, but generally forms about 2 per cent. of the fresh weight of the potato (average of 239 analyses quoted by König,[5] p. 704 = 1·99 per cent.), or about 8 per cent. of the dry weight. Of these about one-half are protein in nature and the remaining half consist of simpler nitrogenous compounds, amides such as asparagine and some amino-acids. In analyses of saline extracts from 10 varieties of potatoes, Neuberger and Sanger[6]

TABLE I

AVERAGE COMPOSITION OF THE POTATO, COMPARED WITH THAT OF WHITE BREAD AND WHOLEMEAL BREAD
(McCANCE AND WIDDOWSON[25])

	Percentage composition				Calories per 100 g.		Reckoned on dry wt.		Minerals, mg. per 100 g.					
									Fe		Ca	P		K
	N	protein* (N × 6·25)	carbohydrate Per cent.	water	fresh wt.	dry wt.	protein Per cent.*	carbohydrate Per cent.	Total	available		Total	available	
Potato,† raw ..	0·34	2·1	21	76	94	393	7·9	87	0·75	0·75	7·7	40	—	570
,, peeled and boiled	0·23	1·4	19·7	80	87	435	6·6	98	0·5	0·5	4·3	29	23	325
,, baked in skin (flesh)	0·41	2·5	25	71	113	389	8·1	86	0·9	0·9	9·2	48	—	680
White bread‡ ..	1·26	(N × 5·7) 7·2	54	32	260	382	10·6	79	1·0	0·9	23	73	69	115
Wholemeal bread§ ..	1·34	7·6	44	37	229	363	12·0	70	2·7	2·2	30	213	136	238

* Reckoning all nitrogenous matter as protein. † "Old," variety not stated. ‡ Average of 9 samples. § Average of 6 samples.

found that on the average 36 per cent. of the nitrogen was protein, 34 per cent. amide, 10 per cent. amino-acid and 23 per cent. basic.

Although the proportion of protein is relatively low—about 5 per cent. on the dry weight—the nutritional value of the total nitrogenous constituents must be high, for the results of human experiments have shown that nitrogenous equilibrium can be maintained on diets containing potato as sole source of nitrogen, even when the amounts ingested provide only 4 g. to 8 g. nitrogen daily. The lengthy experiments by Hindhede[7] are the best-known example; on a diet consisting only of potato and margarine, taken for periods of 100 days and more, the body weight was nearly maintained and positive nitrogen balances were reported when the daily intake of "digestible nitrogen" was as low as 3 g. to 4 g.—corresponding to about 11 g. to 15 g. protein with the additional non-protein nitrogen referred to above. The subject was a man 27 years old, of body weight 70 kg., who consumed 3000 calories daily and led an active life. These experiments and the conclusions drawn have been the subject of lively controversy. In a carefully controlled experiment carried out by Rubner and Thomas[1] lasting 6 days, upon a vigorous man of 75 kg. weight, the diet consisted solely of potato; 2600 g. were consumed daily, with a little salt, the average daily nitrogen intake was 8·7 g. and the average daily nitrogen excretion in urine and faeces 10·6 g., showing a negative balance amounting to about 2 g. nitrogen. Other observations, however, showed equilibrium and even a positive balance. Abderhalden[3] and his colleagues reported nitrogenous equilibrium on an intake of 4·5 g. N daily derived from potato, whereas more than twice the amount of nitrogen was needed when it was derived from white wheat bread or rye bread. This result was in agreement with those of previous tests made by Rubner[8,9] and Thomas.[10] Rose and her co-workers[11] obtained a similar result with a woman subject of 50 kg. weight, who derived the nitrogen of her diet, 4·97 g. daily, from 1500 g. potatoes. More recently Kon and Klein[12] reported tests on two adults, a man and a woman, who lived for 167 days in nitrogenous equilibrium and good health when consuming, respectively, an average of only 5·7 g. and 3·8 g. N daily, all of which was obtained from potatoes.

There is less satisfactory evidence of the value of the nitrogenous constituents of the potato for supporting growth of the young animal (McCollum *et al.*[13,14]; Hartwell[15]). The author, however, has, in unpublished experiments, succeeded in rearing rats from weaning to maturity on a diet containing 1·7 per cent. N (on dry weight), derived entirely from potato, of which less than half was protein nitrogen ; reproduction was successful but lactation failed and no litters were reared. Concerning the nutritive value of the separate non-protein nitrogenous substances in the potato, relatively little is known, but there is no doubt of the high value of the mixture for human nutrition, since the maintenance of nitrogenous equilibrium on potato diets cannot be explained in terms of the protein fraction alone. Kon[16] found tuberin, the protein isolated from potato juice, to be the equal of casein for growing rats and, from a comparison of his results with those of Mitchell,[17] in which the whole nitrogen of the potato was used, concludes that "the non-protein nitrogenous constituents of the potato are well utilized by the rat for repair of the body tissues."

It is frequently asserted that the portions of the potato directly under the skin are richer in nitrogenous substances than the portions nearer the centre of the tuber. The figures given in Table II below are typical of a series given by König[5] (Vol. I, p. 1494) and show, on the contrary, that the latter are actually more nitrogenous.

TABLE II

POTATO. AVERAGE PERCENTAGE COMPOSITION RECKONED ON DRY WEIGHT

	Dry wt., per cent.	Total N	Protein N	Starch	Fibre
Layer near rind ..	24·3	1·40	0·78	75·0	1·86
Central portion ..	19·8	1·85	0·86	74·5	0·88

Vitamins.—Since the potato contains only traces of fat, it forms no vehicle for the fat-soluble vitamins. It is, however, a very useful source of water-soluble vitamins. Although not among the richest foods in vitamin C, and notwithstanding the losses caused in cooking, the relatively large amounts consumed regularly make potatoes of great importance as an antiscorbutic food in winter. The range of vitamin C content in the raw tuber given in the tables of Fixsen and Roscoe,[18,19] 3 mg. to 40 mg. per 100 g., is similar to that given for the carrot, but the values are lower than those given for the turnip and for many leafy vegetables.

Smith and Gillies[20] studied the ascorbic acid content of the potato tuber at different periods of growth and found the highest value consistently declined and after 1 month's to 6 months' storage the average content of ascorbic acid of seven varieties was 28 mg. per 100 g. (range 24 to 34) ; 2 weeks later this value had declined to 16 mg. per 100 g. (range 14 to 22). During subsequent storage the value consistently declined and from 1 month's to 6 months' storage was reduced to about one-third ; for 18 varieties the average content of ascorbic acid fell from 20 (range 13·9 to 26·7) to 6·6 mg. per 100 g. (range 5·1 to 9·5). During the same period the relative proportion of dehydro-ascorbic acid was increased. These facts offer an explanation of the widely differing figures found in the literature for the vitamin C content of the potato.

The losses during cooking in water are due to diffusion as well as to destruction of the vitamin (see Table III, and Olliver[21]), and the advantage in this respect of steaming, as a method of cooking, is evident. Slow methods of cooking, or long periods of "keeping hot," as practised with "cooking boxes," may cause almost complete destruction of the vitamin C, and should be avoided. In some instances, following either boiling or steaming, an apparent increase of ascorbic acid has been found to occur in the cooked potatoes, and sometimes an increase in the total amount present in the cooked potatoes and cooking water. One explanation is that during cooking an ester of ascorbic acid is decomposed, another that the destructive action of ascorbic acid oxidase is inhibited in the cooked vegetable, and a third that ascorbic acid may be more readily extracted from tissues softened by cooking, than from the raw material. This question is admirably discussed by Fixsen.[22]

TABLE III

CONTENT OF VITAMINS AND EFFECT OF COOKING

(FIXSEN AND ROSCOE[18,19]; FIXSEN[22]; OLLIVER[21])

	Vitamin C, mg. ascorbic acid per 100 g.	Vitamin B_1, intern. units per 100 g.
Potato, raw	3 to 40	30 to 60
Peeled, boiled	16 to 32 per cent. destroyed; 20 to 23 per cent. diffused*	25 per cent. loss (probably by diffusion)
Steamed 45 mins., peeled or unpeeled	no loss	
Peeled, boiled 25 mins.—		
2 hours in cooking box	50 per cent. loss	
6 hours in cooking box	90 per cent. loss	

* In some instances an apparent increase in ascorbic acid has been demonstrated.

B vitamins.—The content of vitamin B_1 (aneurine) in the potato appears to be greater than that of white, and about equal to that of wholemeal, bread, when the dry weights of these foods are taken into account. The range in the potato (with dry weight of about 25 per cent.) is given by Fixsen and Roscoe[19] as 30 to 60 international units per 100 g.; for bread (of dry weight 65 per cent.) average values are 25 units per 100 g. for white, and 70 for wholemeal. The losses during boiling of potatoes, unless the time is much prolonged, are probably due to diffusion into the cooking water rather than to destruction of the vitamin by heat.

Of the content of other B vitamins in the potato, there is little information. The riboflavin is stated to vary from 0·01 mg. to 0·2 mg. per 100 g., an amount comparable with that estimated in wheat, or in meat or fish muscle. Nicotinic acid is present in negligible amount, and the potato has been found of little use for prevention of pellagra. Concerning the presence of other members of this group little is known.

The results of the experimental work described above indicate the importance of potatoes in the human dietary. But there is further evidence, which cannot be marshalled in the same precise fashion, derived from human experience. The value of potatoes as a preventive of scurvy in winter, when other vegetables and fruit are not available, has been shown by the serious outbreaks of scurvy which in the past have followed failure of the potato crop in Ireland, as for example in the great epidemic of 1847. Holst and Frölich[23] state that all epidemics of scurvy in Norway in the nineteenth and early twentieth centuries have had a similar history.

There are also certain facts that indicate the advantages of substituting potatoes for cereals in securing better utilization of calcium and phosphorus for nutrition of the teeth. The natives of Tristan da Cunha consume a diet in which potatoes are the principal source of carbohydrate and milk is also abundant, but no grain is grown on the island, of which the remote situation prevents its regular import. Marshall,[24] after examining the teeth of over one-third of the small population, found a remarkable freedom from dental caries even in persons of middle and old age. Other instances can be found in the literature in which introduction of cereals to a race subsisting on meat, fish, and vegetables has resulted in a defective condition of the teeth. It is not possible to discuss here the defects in the mineral constituents of cereals, which are held to be responsible for the failure to nourish the teeth and bony structures adequately, when this type of food forms too large a proportion of the diet. There is, however, enough evidence on these grounds alone to suggest the desirability of substituting potatoes for some at least of the cereals in any given diet.

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Part III

VEGETABLES AS FOOD

(*Papers read at a meeting on 9th April,* 1941)

CHAPTER IX

THE CHEMICAL COMPOSITION AND NUTRITIVE VALUE OF VEGETABLES

By Magnus Pyke

It is with vegetables, defined by the British housewife rather than by the botanist, that this chapter deals. Thus it includes tomatoes but excludes rhubarb. It also excludes potatoes, which are the subject of Part II of this book.

With the exception of the dried legumes, vegetables are usually considered to be an unimportant source of calories in the normal diet. Whereas bread provides 250 calories per 100 g. and beef, mutton, and pork from 200 to 500 calories, boiled cabbage supplies 9, lettuce 12, and spring greens 11 calories per 100 g. Boiled spinach provides 27 calories and the root vegetables, carrot, beet, and parsnip, cooked, give 20, 48, and 61 respectively. Only the cooked legumes—haricot beans, butter beans, dried peas, and lentils, which show figures from 100 to 120 calories per 100 g., can seriously claim to rank as energy foods.

What the percentage of calories in the normal diet derives from vegetables? The B.M.A. "minimum" diet calls for about 100 of its total 3500 daily calories to be supplied by green vegetables, that is, less than 3 per cent. The B.M.A. Individual Diet No. 2, the "better" diet, requires that 620 of its 4000 odd daily calories, or 15·5 per cent., come from vegetables. This higher proportion is achieved by including the high-calorie legumes, dried peas, and butter beans, as well as greenstuff amongst the vegetables. In general, however, the 4-oz. helpings of cabbage and carrots for lunch and of, say, Brussels sprouts and parsnip for supper will only add 124 calories (3·5 per cent. of the day's requirement) to the diet of the most garden-minded individual.

The amount of fat present in green vegetables is too small to affect the calorific value given in tables of food analysis, and the ether extract, which is commonly taken as a measure of fat content, in leaf vegetables is more than half chlorophyll. The remainder is a mixture of true fats, lecithins, waxes, alkaloids, sterols, and carotenoids. Fischer and Hedschel[1] studied the biological breakdown of chlorophyll in human beings. Experiments with a diet consisting mainly of spinach showed that chlorophyll was but slightly changed in the digestive tract. Magnesium and phytol are hydrolyzed from the chlorophyll molecule, but the main structure is practically unaltered. The phylloerythrin formed may be partially absorbed but it is excreted in the bile. McCollum has shown that magnesium is essential to rats and dogs; without it they develop "low-magnesium tetany." Nevertheless, magnesium deficiency is not encountered as a clinical condition in the human subject. Chlorophyll, therefore, does not seem to be of any value in the diet and the current fashion for buying it in tablets at the chemist's shop is apparently without logical excuse. Horwitt, Cowgill and Mendel[2] estimated the proportion of true fat in the ether extract of dried spinach. They concluded that only 41 per cent. of the small amount present was capable of contributing to the energy of the body.

Thus fat is as a rule a minor constituent of vegetables; carbohydrates, however, are more plentiful. In seed vegetables, such as peas and beans, starch or cell-wall carbohydrates replace fat as reserve materials. In roots and subterranean stems also there is a carbohydrate reserve. This is chiefly composed of starch in carrots, sugar in beet, inulin in salsify and artichoke, and less well-defined compounds in turnips. All vegetables, whether starchy or not, contain more or less sugar, the proportion of sucrose to reducing sugar being variable. Organic acids such as malic, citric, and oxalic acids, which are probably intermediary products of carbohydrate metabolism in plants, are also found in small proportions.

Although vegetables as handled in the kitchen normally do not show jelling properties, sugar beets, turnips, and other roots are rich sources of pectin, which is also found in tomatoes. Pectin is probably composed of pentose groups, such as arabinose, combined with galactose and the 6-carbon sugar acid galacturonic acid and can hardly be classed as a true carbohydrate. Pectins, in fact, fall into a class intermediate between the soluble carbohydrates, from which the plant obtains energy, and lignins and cellulose, of which the cell walls are composed.

The nutritive properties of plant carbohydrates have been very thoroughly reviewed by McCance and Lawrence.[3] The vegetable carbohydrates, which are often estimated "by difference," may be conveniently classified into three groups, (*a*) starch, and the soluble sugars sucrose, glucose, and fructose, (*b*) hemicelluloses, and (*c*) fibre. The first group is the most important nutritionally. Starch and soluble sugars are almost entirely digested, absorbed, and utilized. Although the second and third groups, hemicelluloses and fibre, have always formed a part of the human diet, their value in nutrition is more difficult to assess. In young plants the whole of the cell wall is composed of cellulose, which is a polysaccharide made up solely of glucose molecules. Herbivora are the higher animals best capable of digesting cellulose; this they do with the assistance of the micro-organisms living in their guts. Many of the German workers[4,5,6] have found that man is little if at all inferior to the cow in this respect, particularly if the cellulose is fed in a finely divided state. However, although man is capable of utilizing efficiently small amounts of cellulose, he needs enough time to do it. Larger amounts do not spend long enough in his alimentary canal. McCance estimates that the highest amount of cellulose normally ingested is about 9 g.; of this 6 g. is absorbed. Twenty-five per cent. of the energy value is lost by fermentation, so that only 4·5 g. can be assumed to be metabolized. This gives rise to the negligible amount of 18 calories a day from cellulose.

It is only in the young plant that the cell wall is composed solely of cellulose. As the plant grows, other compounds, lignin or cutin, are laid down. Fibre may be defined as the insoluble residue left after treating plant material with water, dilute acids and alkalis, alcohol and ether. Cellulose is included in this miscellany and it is upon the proportion of cellulose in the fibre that its digestibility depends. Lignin is apparently not digested at all, and if it were it would be of no use to the animal, as it is made up of aromatic alcohols which play no part in metabolism. As plants grow older the proportion of lignin in their cells tends to rise. Woodiness in the thicker cabbage stalks, for example, is due to lignin formation.

The middle group of vegetable carbohydrates, the hemicelluloses, which are distinguishable from fibre by their solubility in dilute mineral acids, comprises (*a*) pentosans and related compounds, (*b*) inulin and fructosans, and (*c*) other hexosans. None of these substances is attacked by the digestive enzymes of the human gut.

The pentosans, like cellulose, are only made available to man by courtesy of the micro-organisms in the gut; the quantity with which man can normally cope only provides the negligible amount of about 36 calories a day. Beans contain quite large amounts of hemicellulose; it is the fermentation of this material in the gut by micro-organisms which is the cause of the intestinal distention that sometimes follows their consumption.

In vegetables of the composite family the storage depots contain inulin instead of starch; this yields on hydrolysis fructose, not glucose. Some inulides, notably synanthin and helianthin, contain a proportion of glucose. The vegetables involved are Jerusalem artichokes, globe artichokes, chicory, and salsify. Between 30 per cent. and 40 per cent. of the total carbohydrate of the globe artichoke is inulin. In the autumn the reserve carbohydrate of the Jerusalem artichoke consists almost entirely of inulin, although during the winter some hydrolysis and the formation of inulides occurs.

Inulin is apparently almost completely absorbed in the intestine, and although about 25 per cent. of its calorific content is probably lost by bacterial fermentation, the energy value may be assumed to be 75 per cent. that of starch. In an experiment on this point Bierry maintained a rabbit for 3 months entirely on Jerusalem artichokes. Inulin has some value as a component of diabetic diets. If a patient who is excreting sugar replaces some of the starch in his diet by inulin an improvement always follows and his urine may become sugar-free. On the other hand, however, it has not been proved that inulin can be fed with impunity as an extra to a diabetic whose diet is already balanced.

The third group of hemicelluloses, "other hexosans," form the main carbohydrates of many of the lower plants. Galactans occur in peas and beans, and in seaweeds; agar-agar is probably the best-known example. Carrageen moss contains lichenin and iso-lichenin which yield glucose on hydrolysis. It is doubtful whether these hexosans are metabolized. What energy they may provide is probably again due to bacterial fermentation. Their principal rôle in nutrition, however, appears to be the stimulating effect they produce on the glands of the digestive tract which leads to an increase in the bulk of the fæces. It is this property that renders agar-agar notable.

Thus of the "total carbohydrate" in vegetables part is pectin and lignin which are not carbohydrates at all and of little nutritional value; part is cellulose which is slowly available in small amounts; another carbohydrate fraction is the hemicelluloses which may contribute to our energy with the help of intestinal bacteria. Finally, there are starch and sugar which can be completely digested and made use of.

The vegetables range themselves in order of available carbohydrate content in much the same way as they do for calorific value.

Cabbages and cauliflowers and broccoli and spinach and lettuce all contain less than 2 per cent. The roots, swedes, carrots and beet contain from 4 per cent. to 10 per cent., and the legumes, peas, beans, and lentils again head the list with 10 per cent. to 18 per cent. available carbohydrate.

Stock feeders, who have to deal simultaneously with dried feed such as bran and linseed cake and with succulent materials such as grass and turnips, have adopted the useful expedient of referring to the "nutrient ratio" of a feeding-stuff. The "nutrient ratio" is merely the proportion of carbohydrate and fat to protein. If the percentage of protein only is considered, it is easy to undervalue a wet food, such as grass, in comparison with a dry one such as cottonseed cake. We are in a similar predicament when comparing cabbage, say, with dried peas.

If we take it that a good diet will contain about five times as much carbohydrate as protein, then any food with a nutrient ratio of less than 5 is adding protein to the diet, while a ratio of more than 5 implies a predominantly energy-producing food which will require protein from elsewhere to balance it. It may come as a surprise to realize that, with the exception of beetroot, carrot, spring onion, and parsnip (and, of course, the potato), all the common vegetables may be classed as protein foods, that is, their nutrient ratios are less than 5. Artichokes, asparagus, cabbage, cauliflower, even marrow and turnip are adding protein to the diet, albeit in a small way.

Information on the nature of the proteins in green vegetables was comparatively scanty until a few years ago. Since sheep and cattle could live entirely on grass it was known that the biological value of grass proteins must be good, at least for these species. Recently, however, rapid progress has been achieved in work on leaf proteins. Chibnall,[7] therefore, can now write that the indispensable amino-acids are present in adequate amount. Tryptophan (2·1 per cent. to 2·4 per cent.) and lysine (4·6 per cent. to 6·2 per cent.) compare favourably in amount with the values for casein (1·3 per cent.; 6·25 per cent.) in milk, though methionine is a little lower (2·2 per cent. to 2·7 per cent.). Leucine, phenylalanine, and valine are high. The excellent nutritive value of leaf proteins is thus clearly evident. Experiments with rats by Osborne and Mendel confirm that leaf proteins are of high biological value.

Chibnall divides leaf proteins into three groups, vacuolar protein, cytoplasmic protein, and chloroplastic protein, which differ slightly in composition, most notably in the amount of lysine; this is highest in vacuolar protein. Since leaves are growing organisms, of which protein forms a part of the essential protoplasm, there are, as would be expected, a certain number of building materials and breakdown products to be found associated with the protein in the plant at any time. Leaves and stems contain considerable amounts of amides, amino-acids and other non-protein nitrogenous products, all of which are of some nutritive value.

Most of the leaf vegetables when cooked contain about 2 per cent. of protein (broccoli tops 3 per cent., brussels sprouts 2·4 per cent., cabbage 1 per cent., cauliflower 1·5 per cent., leeks 2 per cent.). Spinach, however, contains 5 per cent. of protein; an individual, therefore, who eats 250 g. of boiled spinach a day, quite a possible amount, acquires 12·5 g. of protein of good biological quality, a substantial addition to his diet.

In contrast to the leaf proteins, proteins obtained from leguminous seeds have been extensively studied for a very long time. Ritthausen isolated the protein phaseolin from beans in 1884. Since that time a formidable list of the amino-acids in phaseolin has been compiled. It can be said in general of the proteins from peas and beans that, while nearly all of these, as far as known, are not wholly deficient in any essential amino-acid, their purified preparations fail to promote normal growth. This disability, however, is apparently overcome by adding a small percentage of cystine. The contribution of the wise manufacturer of baked beans to the war-time diet is therefore clear. Instead of the traditional blanching of his beans, which damages them nutritionally, let him collect barber's-shop clippings to convert into cystine, by the addition of which the food value of his product will be improved.

All that has been said so far shows that the green vegetables are an inconvenient source of calories; their carbohydrate content is low and their fat content lower. Although the protein in greens is a useful contribution to the diet, again the low percentage, which is to say the considerable bulk of vegetables, militates against their use as a major protein source for man in normal circumstances. It is not then as a source of the large-scale food constituents that vegetables are primarily useful, but as a supplier of minerals and vitamins, or, to express it in modern language, as "protective" foods.

The most important "protective" minerals, that is to say those in which the diet is most likely to be deficient, are calcium and iron. As calcium carriers, the green vegetables, though not in the same class as cheese, which may contain up to 1000 mgs. of calcium per 100 g., provide quite useful amounts in the diet. Watercress contains 222, broccoli leaves 160, and spring greens 86 mg. of calcium per 100 g. Spinach at first sight is the vegetable richest in calcium, with 600 mg. per 100 g. However, the proportion of oxalate which appears to be present in traces in most leaf vegetables is quite high in spinach (from 0·29 per cent. to 0·82 per cent. according to different authorities), and it is generally assumed that it is the formation of insoluble calcium oxalate which renders the bulk of the spinach calcium nutritionally unavailable. The literature is not by any means clear on the subject, however. Finke and Sherman[8] found that calcium in spinach was unavailable to rats, while Kohman[9] went even further and suggested that 8 per cent. of spinach in the diet not only supplies no available calcium to rats but renders unavailable much that is consumed in other foods. Workers using children, not rats[10] found, however, that spinach oxalate did not affect the mineral balance. While the matter does not appear to be settled definitely we can perhaps take it that although spinach may not be a source of calcium, it has not been proved to be harmful. According to Horwitt *et al.*[11] about 30 per cent. of the calcium in spinach is available. This is the figure that has been used in Figure 1.

Besides the benefit of the absolute amount of calcium contributed to the diet by green vegetables the proportion of calcium to phosphorus in them is greater than one. Cereals, which form so large a part particularly of poor diets, contain a large preponderance of phosphorus over calcium. It therefore follows that foods, among which are green vegetables, that possess a "favourable" calcium-phosphorus ratio, that is, more calcium than phosphorus, are particularly valuable. The root vegetables and the legumes contain very much less calcium than greens. Phytic acid phosphorus, which is not only physiologically unavailable itself but which also by taking away calcium reduces the calcium-phosphorus ratio of the diet, is absent from spinach and cauliflower. Of roots, turnips and swedes are free from phytic acid; 16 per cent. of the phosphorus in carrot and 31 per cent. in parsnip, however, is combined as phytic acid, while 50 per cent. of the phosphorus in raw beans and the same proportion in peas is similarly unavailable.

As a dietary source of iron, green vegetables are again of importance. The iron in them appears to be completely available; in root vegetables the dietary availability ranges from 69 per cent. for parsnips and 84 per cent. for carrots up to 100 per cent. for turnips and onions. Iron in legumes is least available; only about 50 per cent. in dried peas and beans can be utilized by the body, although this figure rises to more than 80 per cent. if the vegetables are tinned. While the foods richest in iron available to the body are liver with

VEGETABLES AS PROTECTIVE FOODS

The chart shows the proportions of vitamins and the important minerals supplied by 4 ozs. of each vegetable, raw or cooked, as eaten.

From a consideration of various published estimates, the daily human requirements of vitamins and mineral salts have been assumed to be :

Vitamin	A	5,000 i.u. daily.
,,	B	600 ,,
,,	C	1,500 ,,
,,	D	400 ,,
Iron		10—12 mg. daily.
Calcium		800—1,000 mg. daily.

Values shown on the charts are based on these figures.

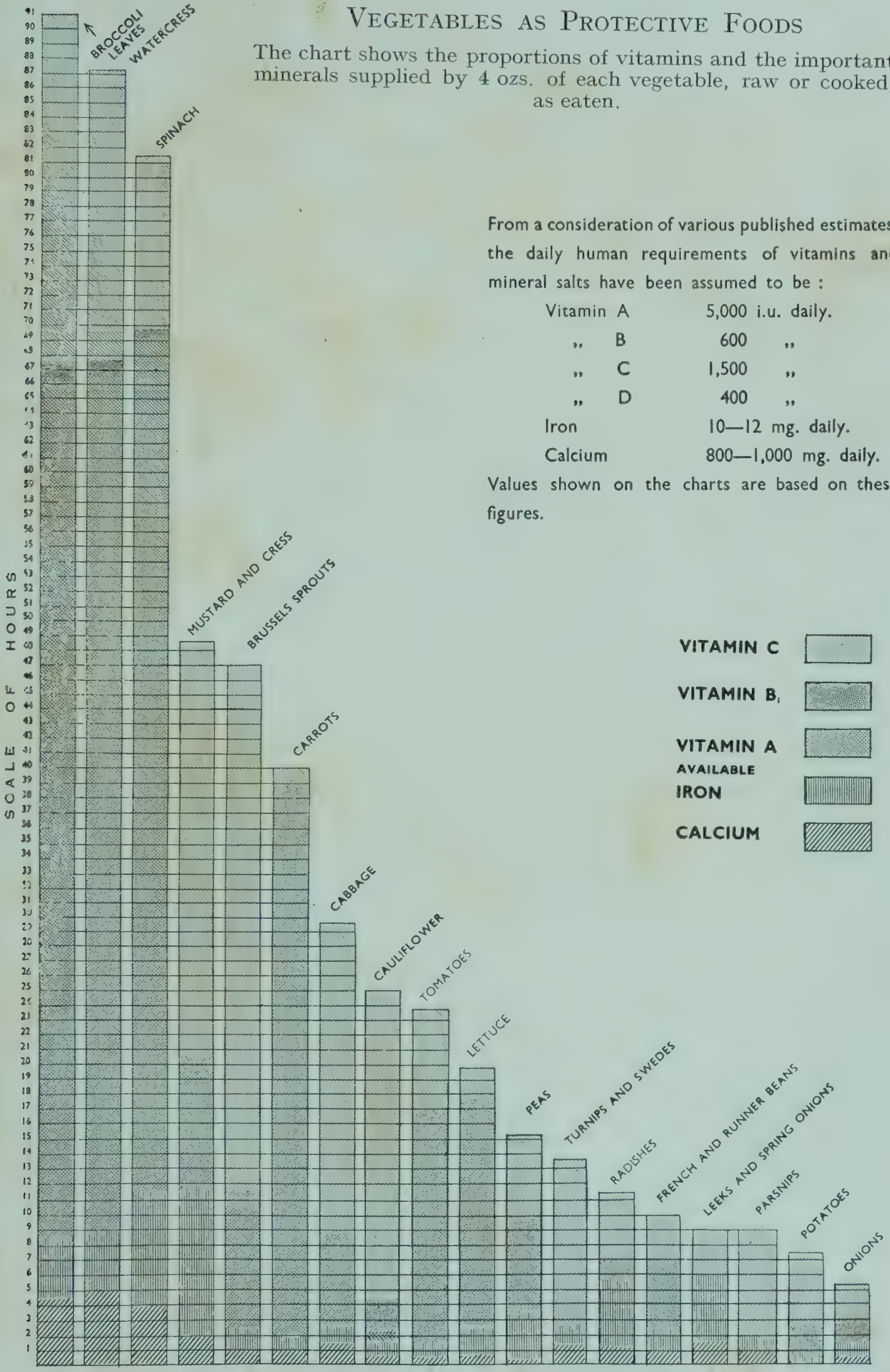

Fig. 1

12 mg. per 100 g., egg with 2·5 and wholemeal bread with 2, spinach is also a useful source, containing about 2 mg. per 100 g. and mustard and cress about the same. These figures refer only to the amount of ionizable iron which it was at one time thought might alone be available to the body. Recent work, however, suggest that our knowledge on this matter is still incomplete. The pulses contain amounts of "available" iron similar to those in the leaf vegetables, and the root vegetables less.

While calcium and iron are the most important minerals from the dietary aspect, since they are most likely to be present in deficient amounts, vegetables have been analysed for other less important factors. The greens of course provide magnesium from chlorophyll. Traces of copper, ranging from 0·6 mg. per kilo in cabbage up to 11 mg. per kg. in carrot have been reported. Zinc is present in onion (14 mg. per kg.), watercress (6 mg. per kg.), and beet (3 mg. per kg.), and manganese apparently varies from 55 mg. per kg. in beet to 4 mg. per kg. in cabbage. When considering these figures it must be remembered not only that the mineral content may vary in different varieties of the same vegetable, in plants grown on different soil and under the influence of half-a-dozen other factors, but also that the concentration may vary from one part of the plant to another. For example, it is well known that the outer leaves of a cabbage, which are usually thrown away, are richer in calcium than the inner leaves. Boron is an element which is necessary in traces for the health of the plant; it is not clear, however, whether it is of any significance in human nutrition.

The mineral content of most vegetables has an alkaline reaction. Boiled spinach is probably the most alkaline; 100 g. contain ash equivalent to 400 ml. of N/10 alkali. This figure is exceptionally high for a leaf vegetable, most of which vary from 25 to 50 ml. (turnip tops 23, lettuce 38, brussels tops 43, broccoli 43). Watercress has an ash which is equivalent to 75 ml. of N/10 alkali. Root vegetables have similar figures (carrot 44, turnip 52, parsnip 67) and the dried legumes somewhat lower; the mineral of baked beans is equivalent to 28 ml. of alkali per 100 g. and of lentils to 2 ml., while that of fresh boiled peas is equivalent to 14 ml. of decinormal acid. Almost the only other common vegetable with an acid mineral balance is mustard and cress, equivalent to 23 ml. of acid per 100 gm. The alkaline acid-base balance, which vegetables in general share with fruits, is in contradistinction to that of most other classes of food, meat, most fish, and most cereals, all of which are acid in balance.

Turning now to the vitamin content of vegetables, we first observe that the green vegetables supply substantial amounts of vitamin A. This is principally present in the form of the vitamin precursor, β-carotene ; β-carotene is always present in green leaves in relatively large quantity and is often accompanied by α-carotene, which only possesses half the vitamin A activity. Since as a general rule the more active β isomer is in excess, it is customary to assume that analytical figures comprising both can be converted to vitamin A as if made up only of β-carotene. This unscientific but convenient and probably not very inaccurate habit has been adopted in the figures which follow, where it has been necessary to supplement published biological assays by my own analytical figures. Although there is controversy on the conversion of figures for carotene into international units of vitamin A, a glance at published tables shows that such wide variation may exist between specimens examined by different authors that no great error is likely to be introduced in converting my own carotene figures to vitamin A by the theoretical factor. For carotene also the concentration from one specimen to another is closely governed by the greenness of the vegetable and quite large variations may exist as well between different leaves of the same vegetable. It is with these points in mind that the figures shown in Figure 1 are put forward in the hope that they represent at least the correct order of vitamin A present in each different vegetable.

Green vegetables are not particularly good providers of vitamin B_1, although they contain more than enough to cope with the number of non-fat calories they bring with them. Since vitamin B_1 deficiency is caused by an excess of carbohydrate calories in the diet unbalanced by vitamin B_1, the small amount of vitamin B_1 brought to the diet by vegetables is a clear gain for the body. Dried pulses, according to the tables, are a much richer source of vitamin B_1 than green vegetables and contain up to 400 international units per 100 g. I was disappointed, however, to find on analysis that about 90 per cent. of this vitamin content is destroyed or lost before these vegetables reach the table. Vegetable foods with one exception contain no vitamin D but they are important providers of vitamin C in the diet.

A number of the less well understood vitamins, the importance of which in the diet it is harder to assess, have been found in vegetables. Lettuce oil has been used as a rich source of vitamin E ; riboflavin and vitamin K have been isolated from alfalfa ; vitamin P is closely associated with the flavone pigments which are fairly widely distributed in plants, and so on.

The place of vegetables as "protective" foods in the diet is shown in the three diagrams. Figure 1 shows the relative importance of each vegetable as a contributor of vitamins A, B_1, and C, iron, and calcium. It is these constituents above all others that establish the value of vegetables to us. I cannot claim the credit for this neat method of presenting the data, which must go to my associates in the Research Laboratories, Vitamins, Ltd., Hammersmith, to whom I should like to express my gratitude. The figures are principally derived from Fixsen and Roscoe[12] and McCance and Widdowson.[13] Only when these tables were lacking have analytical figures of my own been included.

The amount of each vitamin and mineral present in 4 oz. of each vegetable has been expressed as the number of hours' supply provided. The figures for the 24 hours' requirement have been derived, rather arbitrarily it must be admitted, by amalgamating the daily human requirements assessed in the British Medical Association "minimum diet," the "diet of moderate cost" of Stiebeling, and the marginal and optimal figures of Bacharach and Drummond.[14]

I think the chart shows very clearly the difference in importance of vegetables which are often grouped together. The figures, of course, are merely averages; we shall read in later chapters about the effects of storage, cooking, and other factors upon them, but as they stand they show that vegetables with dark green leaves are the best. The more sophisticated cabbage with its blanched white heart, although still a valuable source of vitamin C, lacks the high vitamin A stores of broccoli* leaves or spinach.

This greenness of the greens we eat is of very great importance. I will illustrate this point with some figures. I was given some broccoli flowers to analyse ; these, like cauliflowers, were surrounded with stumps of leaves, trimmed off in the usual way by the greengrocer. The heads contained 0·8 mg. carotene, the vitamin A active substance, per kg. The pale green leaf stumps contained 3·9 mg. per kg. The unmutilated leaves of broccoli, like the dark green leave of purple sprouting broccoli or curly kale, may contain 40 mg. to 50 mg. per kg. of carotene, ten times as much.

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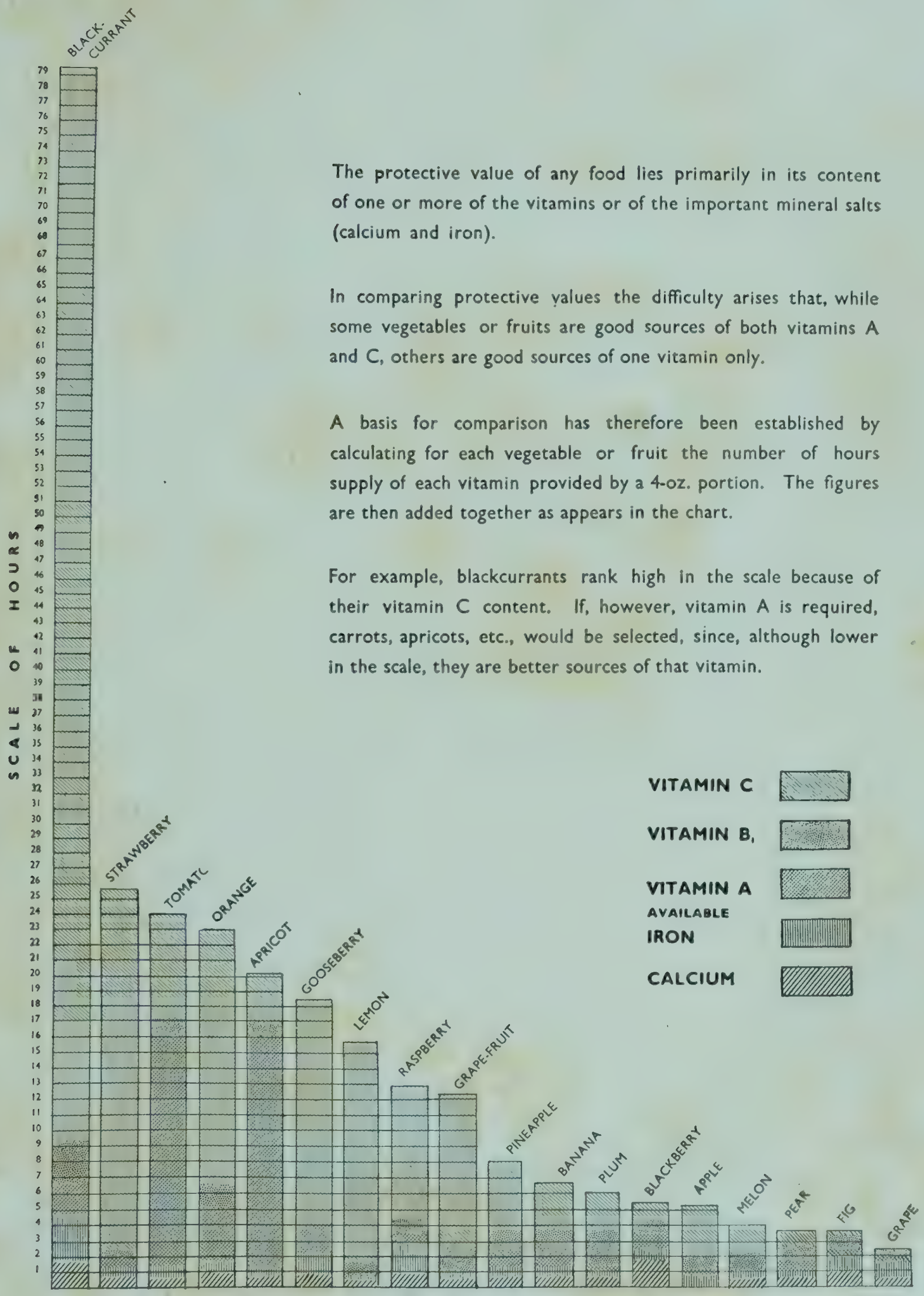
* There is great confusion about "broccoli." Miss M. Grant has visited five greengrocers' shops and obtained as broccoli three varieties of plant, "purple-sprouting broccoli," "white broccoli," and "winter cauliflower." According to Miss Widdowson, none of these was the vegetable listed by McCance and Widdowson[13] as "broccoli tops." The vitamin figures for broccoli leaves in the chart above refer to the leaves of purple-sprouting broccoli, the calcium and iron figures are derived from McCance and Widdowson. In view of the very high nutritive value of vegetables of this nature it is most desirable that the confusion of nomenclature be authoritatively cleared up.

The high ranking of mustard and cress is perhaps worthy of comment. If the agriculturists can provide the seed, town dwellers could supply themselves with substantial amounts of vitamins and minerals by growing this crop in their houses. Tomato is more valuable than its place in the table might suggest, as it is popular and weighs heavy. Carrot also, though a source of vitamin A, does not rank outstandingly high. It may certainly be tasty to eat, but even its calorific content of 20 Calories per g. does not help it to compete with brussels sprouts, which contain 17 Calories per 100 g., while boiled spinach contains 27 Calories per 100 g. The dried pulses, peas, beans, and lentils, have been omitted from this chart. While they are indeed useful sources of second class protein and of calories they do not supply vitamins A or C, and as I mentioned before, their vitamin B_1 is mostly lost in cooking. A number of other vegetables are missing from the chart. Asparagus, celery, cucumber, marrow, and pumpkin have been omitted because they are of such low nutritional value that they hardly rank as food. Mushrooms and other edible fungi have also been left out since, although strictly vegetables, they form a class of their own. However, they contain a small amount of vitamin A, a small amount of vitamin B_1, a very small amount of vitamin C, and, exceptionally for a vegetable, a little vitamin D. The edible weeds, nettles, dandelions, ground elder, cowslips, sowthistles, and many others have also been omitted. Nettle and dandelion leaves, and so on, although similar in composition to the other leafy plants shown on the screen, are not so good as the best. Until there is reason therefore to grow them as food crops they hardly come within my terms of reference.

As can be seen from the chart, the onion in war time, at the bottom of the list, is in bad odour. Nutritionally the onion and the apple might be bracketed together. The doctor is kept away very easily if an apple will do it. The apple contains as few nutritional qualifications compared with other fruits as the onion does compared with other vegetables. Fruits are the other principal substantial contributors of vitamin C to the diet besides vegetables and Figure 2 shows a similar comparison between different varieties of fruits. With the exception of apricot and tomato, now masquerading under its botanical classification as a fruit, both of which contain carotene, none of this class makes any substantial contribution to the diet other than vitamin C. And, with the exception of black currants, even in this respect fruits cannot compete with vegetables as protective foods. One point about this chart may give rise to a twisted smile. When our friends are ill in hospital the fruit we take them

Fruits as Protective Foods

The chart shows the proportions of vitamins and the important minerals supplied by 4 ozs. of each fruit, raw.



The protective value of any food lies primarily in its content of one or more of the vitamins or of the important mineral salts (calcium and iron).

In comparing protective values the difficulty arises that, while some vegetables or fruits are good sources of both vitamins A and C, others are good sources of one vitamin only.

A basis for comparison has therefore been established by calculating for each vegetable or fruit the number of hours supply of each vitamin provided by a 4-oz. portion. The figures are then added together as appears in the chart.

For example, blackcurrants rank high in the scale because of their vitamin C content. If, however, vitamin A is required, carrots, apricots, etc., would be selected, since, although lower in the scale, they are better sources of that vitamin.

Fig. 2.

VEGETABLES COMPARED WITH OTHER PROTECTIVE FOODS

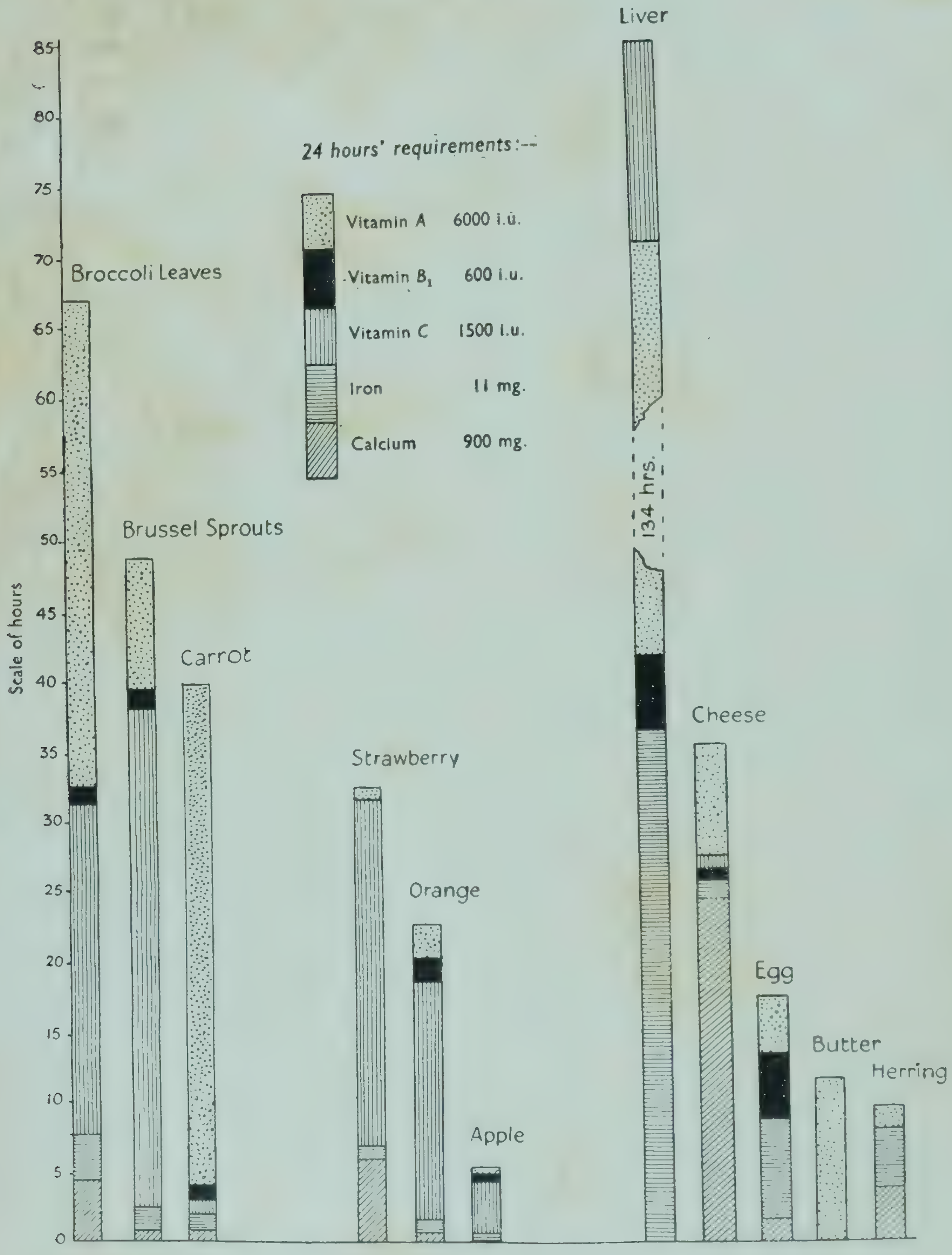


Fig. 3

to stimulate their strength is—grapes. Fifteen per cent. of sugar indeed, but very little else.

As contributors of vitamin C to the diet vegetables, with fruits, virtually stand alone. Figure 3 compares vegetables with fruits and with some other protective foods of quite different classes. With the exception of liver, which provides vitamins A and C and iron in prodigal amounts, none of the other foods overshadow vegetables even in their own speciality and all are deficient in vitamin C. On the other hand, cheese, egg, butter, and herring contain vitamin D, which is absent from vegetables.

With all this evidence before us, what conclusions can be drawn about the place of vegetables in the war-time as distinct from the peace-time diet? First, they must provide all the vitamin C we need, including what is normally supplied by imported fruit. Half a pint of imported orange juice only contains the equivalent vitamin C of 4 oz. of home-grown boiled cabbage, and for use in infant feeding swede juice contains 50 per cent. of the vitamin C of orange juice. Secondly, vegetables must provide much of the vitamin A we normally get from butter, eggs, and fish. It can be seen from the chart that vegetables also make substantial contributions to the iron and calcium requirement of the diet. These minerals, however, are not so important as vitamins. In peace it is more palatable to obtain one's dietary mineral requirements from one's diet, but if the exigencies of war demand it, there seems to be no insuperable chemical objection to the consumption of both these metals in an inorganic form. Forty million people eating 11 mg. of iron a day only need 3½ tons of iron a week.

Although green vegetables, in the form in which they are customarily eaten, are too bulky to be used as convenient sources of protein, yet the protein they provide appears to be of high biological value. Dried grass, and more especially dried clover and alfalfa, which are used for stock-feeding, are good sources of protein. Whether such dried material could be used in human feeding I do not know, but with any shortage of protein it is worthy of consideration. For example, on a dry-weight basis, turnip tops contain 37·5 per cent. of protein.

Drying might also be employed in concentrating the primarily carbohydrate-containing vegetables, carrot, beetroot, and parsnip. Dried carrots, for example, form a sweet powder of high calorific value. Whether it is worth while to produce such a food in competition with cereal grains, which form our present main source of calories, is a different matter. Peas and beans, of course, as they are usually served, already have quite a high calorific content. They also provide useful amounts of protein which, although not of first-class character, can play a valuable part in the diet if supported by more complete proteins, for instance, from milk or green vegetables.

To summarize: with the exception of the dried pulses, vegetables are primarily "protective" foods. They can supply to the diet all the vitamin C, probably all the vitamin A, a substantial proportion of the iron, and some of the calcium needed for good nutrition. Vegetables will play their full part in an intelligent war-time diet provided we look after three things, (*a*) choose the crops to provide a maximum yield of vitamins per acre, (*b*) waste and destroy as little vitamin as we can in storage, preparation, and cooking, and (*c*) plan intelligent bills of fare to supply the vitamins we want up to the amount our bodies need.

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CHAPTER X

THE PLANNING OF VEGETABLE PRODUCTION

By H. V. Taylor

A perfect plan of vegetable production could be arranged provided knowledge was available of the existing production and nutritionists were able to define fairly precisely the vegetable requirements of the population for each particular kind. It is somewhat doubtful whether precise information is available on either of these aspects.

Vegetable Supplies

(*a*) *Statistics of output.*—The compilation of reliable statistics of the production of vegetable crops is a matter of some difficulty, for there is no day in the year when a census of production could be taken that would include every vegetable crop grown during the year. It is even more difficult to obtain figures for the output of vegetables from private gardens and allotments. At the best the census of production is in part a return and in part an estimate. Such a census could be compiled but it is doubtful whether it would give the required information. It would be a record of the gross quantity of vegetables sent to the market, which is much larger than the quantity of vegetables eaten.

(*b*) *Dietary survey.*—The result of recent dietary surveys suggests that the annual consumption of vegetables by human beings in the United Kingdom is about 1,850,000 tons. This gives a daily consumption per head of only 3·7 oz. No figures are available to show how the figure of 1,850,000 tons was obtained. Far more vegetables than this are produced in the country, so that it is clear either that there is a considerable wastage of fresh vegetables or that the edible fraction is very much smaller than the gross total.

Even with these figures before us it is not possible to draw up a plan of vegetable production until other factors have been considered.

Vegetables in Suitable Variety

During 1939 a Committee was concerned with the preparation of a Bulletin designed to give the best advice on vegetable production in gardens to supply the household. The reports and research papers of workers on nutrition were consulted and it seemed that green vegetables were stressed by every writer, green salads for preference, and, if these were not available, then green vegetables. Proteins and carbohydrates could be obtained in greater abundance from other foods; the vegetables were required chiefly to provide minerals and vitamins.

The Bulletin published under the title of *Food from the Garden* gave plans for cropping the gardens and recommended green salads and green vegetables during the summer and autumn and sufficient Brussels sprouts, late savoys, cabbages, and kales to give a daily supply of green vegetables throughout the winter and spring. These recommendations were, in fact, based on the latest scientific findings.

Some 400,000 copies of the Bulletin were in circulation and, being a Government document, it naturally came in for public criticism. One earl, well known as a champion of science as applied to agriculture, wrote to *The Times* "that all this production of green stuffs (mostly water) was sheer waste; why not heed the teachings of science and plant the gardens to potatoes, for potatoes gave the greatest supply of real food."

Next another contributor suggested that his lordship was incorrect, for every gardener knew that parsnips gave an even larger quantity of food, and gardens should be planted with parsnips. A third contributor said both were wrong for the maximum amount of food could be obtained by growing Jerusalem artichokes.

Soon after these letters had appeared I was addressing an audience at Bournemouth and at question time one man quoted the letters and asked for advice whether he should grow potatoes, parsnips, or artichokes. I asked in reply, did he like eating these vegetables, and was told "I dislike artichokes, loathe parsnips, but enjoy potatoes." These cases are cited to illustrate the first point of importance, namely, that it is idle to grow types and kinds of vegetables unless they are liked and appreciated as *food*; otherwise wastage occurs. If spinach, carrots, or green crops are not popular as food, it is idle to increase their production.

Incidentally it should be mentioned that 100 demonstration gardens have been selected throughout England; these have been planted as advised in *Food from the Garden*. Records are kept of the crops gathered week by week and nutritionists examine the records to see whether the planning is sound for giving a balanced supply of minerals and vitamins and, if not, to suggest modifications. Some suggestions have been put forward for planning the vegetable crops.

It has been suggested by growers that Brussels sprouts should be eliminated and more cabbage produced. Brussels sprouts occupy 33,000 acres of land and much less would be required to produce an equal weight of cabbage. The farmers would save land and labour by this course, but would the public appreciate such a change?

The existing acreage to cabbage exceeds 100,000 acres grown specially for home consumption. Cabbages are always abundant; they are tolerated (rather than enjoyed) by the public, and it is doubted whether more cabbage would be eaten even if the supply of Brussels sprouts was reduced. The Brussels sprout plant gives a supply of delicious small sprouts from October till the end of March and the plant is resistant to the heaviest frost. This case is cited to stress the importance of not being misled merely by weights. Other factors are important. The palate may tire of the same foods and appreciates variety. To secure maximum consumption of green crops, cabbages, Brussels sprouts, savoys, kale, etc., are all needed and each should find its place in the programme of production.

HERBS AND VEGETABLES FOR FLAVOURING

In peace-time, the supply of culinary herbs and flavouring material, such as sage, mint, thyme, mustard, was usually generous and often much was wasted; thus it seemed reasonable on the outbreak of war to utilize some of this "herb" land for the production of more important food crops. In consequence about 20 per cent. of such land was diverted during 1940 and for a time the herb supplies seemed adequate and the action seemed justified, but towards the close of the year difficulties arose. Meat, cheese, eggs, etc., came forward in diminished supply and people had to be content with meals made from offals and less choice joints. The sausages contained less meat and vegetable soup and vegetable pies took the place of meat soups and joints. The flavours previously supplied by meat and cheeses had now to be supplied by herbs and mustard; the demand for these rapidly increased and unfortunately more land will have to be found for these crops. Probably over 50,000 acres of land has to be spared for herbs to make food attractive to the nose and palate. The parsley, of course, can be justified on nutritional grounds, but others that are not are required and must be produced.

PICKLES

So far as I am aware no authority has attributed any great nutritional value to pickles or to sauces. In peace-time, these are regarded as desirable adjuncts to meals of cold meats and particularly so when people are indulging in snacks at the bar. It might have been expected that sauces and pickles could be dispensed with in war-time, but the contrary seems to be the case. Pickles are needed by the Army, the Navy, the Air Force, and the general public, seemingly in quantities much in excess of those normally enjoyed. Perhaps they give a zest to the duller meals. This appreciation of sauces and pickles in war-time brings another new burden to our vegetable programme, for in peace-time the factories obtained the raw materials from overseas. New land has to be spared to supply the pickle crops. In 1941 several thousand acres are to be planted to "pickling" onions and to garlic, 1200 acres to "pickling" cauliflowers, 100 acres to gherkins, 200 to red cabbage, and over 11,000 to mustard.

GREEN CROPS

Bearing in mind the importance of palatability and aroma it is now possible to examine the different vegetable groups and give them a proper place in the programme. The groups are: Greenstuffs, the Protein Crops (Pulses), Carrots, other Root Crops, Tomatoes, etc.

Green crops, which comprise cabbage, savoys, Brussels sprouts, kales, spinach, and lettuces, are generally in very large supply from June to January and probably sufficient is eaten in these months. Supplies are less, however, during March, April, and May as the public use (and seem to prefer) broccoli, Madeira beans, sea-kale, asparagus, and root vegetables. Perhaps a greater production of kales and late savoy cabbages and sprouting broccoli should be made in war-time and an increased consumption of these in the late winter and early spring would have a beneficial effect on health. These green crops form the largest group in the programme and amount to a quarter of the total vegetable acreage.

CAULIFLOWERS

Summer cauliflowers and winter broccoli are in continuous supply and are important vegetables and this group takes the second place, ranking in importance after green stuffs. In the writings and reports of scientific workers the position of cauliflowers, including hardy winter kinds (broccoli), remains undefined. Is it that the nation is wasting too much land in producing cauliflowers, or that nutritionists have not as yet decided whether cauliflowers are a desirable vegetable of national importance? There is no doubt that cauliflowers are popular with the public and are eaten in preference to cabbage and the like. People tell me they can make a meal off a cauliflower, so I commend this group to the nutritionists for further consideration and pray for a little guidance from them.

CARROTS

In peace-time the production (and consumption) of carrots was approximately 160,000–180,000 tons or an average of 3½ oz. per head per week. The supply in 1940 was rather more than double, for a crop of record size was produced. By publicity, demonstrations, and speeches the Minister of Food has coaxed the public to eat more carrots than ever, probably 50,000 tons per month. A larger acreage of carrots is planned for 1941 and the problem will be that of coaxing the public to eat still more. The nutrition panel might turn its attention to the ways and means to be adopted to make the public conscious of the value of carrots—for it is assumed that the panel is convinced of the great virtue that lies within this homely vegetable which the donkey has appreciated since the Dark Ages. Other root crops—beet, parsnips, turnips, and swedes—are grown in vast quantities, either for human consumption or for livestock, and as the livestock is reduced, further supplies will become available for human consumption.

PULSE CROPS

Peas and beans are grown in some quantity, but it seems that these protein foods are not produced in sufficient amount in the United Kingdom and that an increase is desired. Arrangements are being made to increase the area to dried peas in 1941, and probably still further increases should be made in 1942. The yield per acre (15 cwt.) is not heavy, so the further expansion would depend on the importance attached to more protein foods by those who advise the nation on nutrition.

TOMATOES

In normal years, approximately two-thirds of the total consumption came from the Canary Islands and the Channel Islands; as these imports are no longer available, the supplies and consumption are much reduced.

The English crop is produced in glasshouses and there were practical difficulties in building large areas of glass during wartime to secure an increase. An increased crop was secured, however, by compelling the flower growers to give over houses to tomato production. The quantity available will be less than normal and still much less than should be available, since citrus fruits are no longer available to many people. In 1941 and 1942 further increases were made by the flower growers both under glass and in the open.

The supply between May–November is larger than pre-war, but still insufficient, since the demand has increased.

Miscellaneous Vegetables

A few words on miscellaneous vegetables conclude this paper: these are asparagus, sea-kale, celery, and rhubarb. Have these vegetables any value? Asparagus is certainly appreciated by the gourmets, but this is probably because of its elusive flavour rather than for any nutritive factor. Some of my friends insist that asparagus is the only vegetable worth eating—and there is never any difficulty in finding buyers. Similarly, sea-kale and celery are regarded as vegetables fit for the gods and eaten with real relish, yet their nutritive value is said to be very low. Rhubarb, of course, is used early in the year as a substitute for fruits before these are in season. The present view seems to be that all these vegetables are not so important as some others in war-time and their cultivation could be reduced, yet the public can never get sufficient of these.

Conclusion

These remarks may be sufficient to indicate the complexity of the vegetable programme and to show that it could not be arranged with only one feature in mind. The selection of only those vegetables that stand high on the list of nutritive vegetables, whether viewed from the angle of protein, carbohydrates, minerals or vitamins, would not prove popular with the public. Variety in kinds is undoubtedly of great importance, also the inclusion of vegetables that possess an agreeable flavour and pleasing smell.

The vegetables in largest supply should be the green stuffs; though usually sufficient, supplies are deficient during April and May and increased acreages to late savoys, kales and winter spinach, and sprouting broccoli are indicated. The second largest group, the cauliflowers and broccoli, though much appreciated by the public, have not been recommended by the nutritionist—probably because they have received insufficient study. The carrot acreage and consumption are increasing as a result of propaganda extolling the value of the vegetable. The production of pulse crops is on the low side. Since supplies of meat, fish, cheese and eggs are declining, an increase in the acreage to pulse crops may be necessary.

The public still need and use large quantities of crops for flavouring purposes and though these may have little nutritive value, their production in sufficient quantity is undoubtedly worth while if not absolutely necessary.

CHAPTER XI

THE EFFECT OF COOKING ON THE NUTRITIVE VALUE OF VEGETABLES

By Mamie Olliver

To assess the dietetic value of any foodstuff it should be considered in the form in which it is likely to reach the consumer. This simple but vital point is often neglected in nutritional surveys, since scientific interest is so frequently confined to the study of the natural product itself. Consequently, the two great classes of plant foodstuffs—fruits and vegetables—are usually grouped together when their nutritive value is under consideration, irrespective of the fact that, whilst fruits are usually eaten raw, vegetables are rarely eaten without some form of preliminary heat treatment, such as cooking or canning. It is the value of *heated* vegetables which is of economic importance, and in this paper the effect of domestic heating or cooking on vegetables is to be discussed.

It is obviously impossible to consider all the various methods by which a vegetable may be cooked, and it is therefore proposed in the present survey to regard domestic cooking of vegetables as applying either to boiling or steaming (wet methods of treatment), or to frying or baking (dry methods of treatment). Intermediate methods, such as conservative cooking, will not be discussed. Also, since the term vegetables usually includes all edible plant products other than fruits, many different organs, such as leaves, buds, stems, roots and tubers, will have to be considered. The effect of cooking on each type must of necessity be somewhat different. For present purposes, therefore, it is proposed roughly to group vegetables into two classes, i.e., green leafy vegetables and roots and tubers. Reference will also be made to legumes and flower heads, which will be considered as a sub-group of the former class.

1. Preliminary Treatment of Vegetables

In domestic cooking the housewife first prepares the vegetables by removing the parts she considers unsuitable for use. Root vegetables are peeled or scraped, and the outer discoloured leaves and tough stems of green vegetables are removed. In this process a considerable amount of tissue may be lost. McCance, Widdowson and Shackleton[1] give figures for waste as percentage of purchased weight in vegetables used for boiling and show that with leafy greens the figures vary from 21 per cent. to 61 per cent. with a mean value of 25 per cent. In root vegetables the range given is 14 per cent. to 26 per cent. for "peelings," whilst a loss of only 4 per cent. or 5 per cent. is found for "scrapings." Fresh peas and broad beans show 63 per cent. to 71 per cent. waste respectively. The rigorous trimming of green vegetables may result in a significant nutritional loss, since the discarded tissue is usually similar in composition to the edible portion. Cowell[2] showed that the outer green leaves of cabbage, which are usually discarded, contain an even higher concentration of calcium than do the inner leaves, and McCance *et al.*[1] showed this to be true for other mineral salts. The discarded leaves from sprouts and also from cabbage have been found no less rich or even richer in ascorbic acid than the inner edible leaves. There is little doubt that the housewife is inclined by habit to be wasteful in preparing green vegetables and may throw away useful tissue merely because it does not look fresh and crisp. Stems, too, may contain significant quantities of mineral salts and vitamin C. It is, however, probably false economy to use them when they are tough and stringy, since the cooking will have to be continued after the leafy parts are already cooked, and consequently the amount of salts and ascorbic acid leached into the cooking water will increase. Peeling of potatoes removes tissue which is, for all practical purposes, very similar to the central portion.[3] The vitamin C content is, however, distinctly lower in the peel than in the central portion of the potato (Table I); even so, approximately 15 per cent.

TABLE I

THE DISTRIBUTION OF ASCORBIC ACID IN INDIVIDUAL POTATOES AND PARSNIPS

	Mg. ascorbic acid per 100 g.	
	Peel	Peeled tissue
Potatoes—		
Freshly dug	24	36
(Variety: King Edward)	24	33
	25	34
Old. Lifted and clamped 1 month	12	20
(Variety: King Edward)	12	17
	15	19
Old. Lifted and clamped 5 months	6	7
(Variety: King Edward)	7	8
	6	7
Parsnips—		
Old. Lifted and stored 4 weeks	4	5
(Variety: Tender and True)	5	7
	4	6

Loss of total ascorbic acid due to peeling = approximately 15 per cent. for both potatoes and parsnips.

of the total vitamin C of the potato is lost in this way. The possibility of conserving the nutritive substances by cooking root vegetables in their skins will be discussed later. The cultivation of varieties of vegetables in which the waste is reduced to a minimum, e.g., stringless beans, is an interesting sidelight on the problem of wastage from preparation of the material for cooking.

Preliminary soaking of vegetables before cooking was at one time considered to cause a very great loss of the soluble constituents of vegetables, but it has been shown[1] that, for all practical purposes, the losses on soaking raw vegetables are small. This applies also to the soaking of dried legumes.[4,5]

2. Effect of Cooking on Vegetables

(a) *Cellular tissue*

One of the chief aims in cooking vegetables is to soften the cellular tissue. It is sometimes claimed that cooked vegetables place a greater mechanical strain on the digestive organs than do raw vegetables on account of the increased bulk due to absorption of water in cooking. This argument is not tenable, however, since the change of weight in raw leafy vegetables after cooking and draining is slight, and root vegetables frequently show a loss in weight on steaming. Very little work has been carried out on the digestibility of raw as compared with cooked plant tissue since the end of the last century, but Eimer[6] states that greater work of digestion is involved on the raw than on the cooked tissue. This worker, however, found that cooked vegetables were only slightly better digested than raw vegetables and concluded that the main difference between cooked and uncooked plant tissue lay in palatability and not in utilization. Kohman, Eddy, White and Sanbourn,[7] working on rats, found that cooking had beneficial effects on the physical structure and texture of foods, including vegetables.

If the softening of the cellular tissue is carried out by the use of hot water, then the possibility arises that the water soluble contents of the cells may be leached into the cooking water. The extent and importance of such losses will be discussed in the following sections.

(b) *Starch and Sugar*

Cooked starch is more digestible than raw starch, since the grains are partly gelatinized by wet or dry heat. With dry heat (e.g., in baking potatoes) the starch of the outer tissue may be converted into soluble starch and dextrins. Lampitt and Goldenberg[8] discussed the effect of cooking on the starch of potato, and their chapter should be consulted for a review of work on the physico-chemical changes taking place during the cooking of this vegetable.

Sugars, being readily soluble in water, may be leached out of the tissue on cooking, and as much as 30 per cent. to 70 per cent. of the total sugar may be extracted during the normal boiling of vegetables.

(*c*) *Nitrogen*

The nitrogen of vegetables is present mainly as soluble amide and peptide nitrogen, and in boiling some of the total nitrogen may, therefore, be lost owing to extraction into the cooking water. This subject has not, however, been studied in any detail and the dietetic importance of this leaching cannot yet be properly assessed.

(*d*) *Mineral Salts*

The most comprehensive investigation into the effect of cooking on the mineral salt concentration of vegetables is that carried out by McCance, Widdowson and Shackleton.[1] Reference should also be made to their report for a summary of the existing literature on this subject prior to their own work. The findings of McCance and his co-workers can be briefly summarized as follows.

Boiling vegetables in water results in the leaching of variable percentages of the mineral salts into the cooking liquor. Sodium, potassium, and chloride ions usually show the greatest loss, but the extraction of iron and magnesium may be as great as that of the alkali metals. There may be no loss at all of calcium on cooking in distilled water, and there may even be absorption of calcium on boiling in tap water.[9] Conditions affecting the extent of leach were studied and it was found that the variation in the volume of water used for a given weight of vegetables made surprisingly little difference. The authors, however, recommend that the amount of water should be kept as small as possible to reduce extraction to a minimum. Under normal conditions of cooking the percentages of extracted mineral salts increased with time, and overcooking is, therefore, to be avoided. The common practice of adding sodium bicarbonate to the cooking water in order to preserve the colour of green vegetables was studied, and was found to make very little practical difference to the losses caused by leaching. In this connection it should be mentioned that the composition of the water used for boiling seems to affect the extractive loss, and to some extent this appears to be due to variation in the time required to cook the vegetable when waters from different sources are used.[10,11]

The skin of the potato was found to be impermeable, and, provided the skin of the tubers was initially unbroken, no extraction of any salts took place until the skins burst. It is, however, more common practice for the housewife to peel and also to cut potatoes before boiling. Since the smaller the piece the greater will be its relative surface area, a greater relative loss was to be expected from the smaller than from the larger pieces. This was confirmed experimentally, and rapid extraction of the cell constituents was found when vegetables were cut into very small pieces and boiled. This method is usually only adopted in soup making, when there will, therefore, be no loss to the consumer. The actual dietetic importance of the extraction of mineral salts on normal boiling of vegetables, even when the cooking liquor is drained away, is, however, small. A table is given in the report which shows that the approximate loss of the different mineral salts from average-sized portions of various cooked vegetables is a mere fraction of the daily intake. It is concluded that the losses caused by extraction on boiling both green and root vegetables are not dietetically significant.

In steaming root vegetables a loss of approximately 20 per cent. of the weight was found, and this was accompanied by a corresponding percentage loss of soluble salts. It is suggested that this is caused by the collapse of the ligno-cellular walls under the influence of moist heat, with subsequent expression of the cell juices. Sprouts lose less than 5 per cent. of their soluble salts when steamed, and the theory is advanced that the expressed cell contents are retained between the leaves of the individual buds.

A point of some interest has been raised by Fyler and Manchesian.[12] They found that peas and asparagus, harvested and stored under suitable temperature and humidity conditions for over 48 hours, retained more of their mineral constituents when cooked, either by boiling or steaming, than when cooked immediately after harvesting.

Dry methods of heat are usually applied only to roots or tubers such as potatoes, and result in a decrease in weight of the vegetable. This is due entirely to evaporation (as much as 70 per cent. of the moisture content of potato chips may be lost after about seven minutes' frying), and all the mineral salts are retained.

The work of McCance and his colleagues has shown that cooking for normal periods has little deleterious effect on the nutritive value of vegetables, so far as mineral salts are concerned. In addition, their investigations into the behaviour, under various conditions of cooking, of the water soluble constituents of plant tissue have laid the foundation for the more recent work on the effect of cooking on the water-soluble vitamins.

(*e*) *Vitamins*

Pro-vitamin A (*Carotene*).—Carotene is relatively stable to heat, except in the presence of much oxygen, and is also insoluble in water. Consequently, vegetables after cooking have been found, with a few doubtful exceptions, to retain a high percentage, if not all, of their carotene potency. Hoff[13] has investigated spinach, Coward and Morgan[14] carrot, cabbage, and rubber beans, and Willstaedt and Jensen[15] carrot and spinach. References to vegetables less common in English households, showing similar results, may be found in the tables compiled by Fixsen.[16] These tables form an excellent review of literature published up to 1938 dealing with the effect of cooking on vitamins in general. Mayfield and Richardson,[17] in animal feeding tests, found that cooked green beans yielded more units of vitamin A than did the raw green beans. They attribute this finding to the effect of cooking on the digestibility of the vegetable. Cooking, they suggest, decreases the toughness of the vegetable and so makes more of the pro-vitamin available.

The absorption of carotene from raw and cooked vegetables has been studied by various investigators with somewhat conflicting results. Wilson and his co-workers[18] found carotene to be absorbed equally well from raw carrots and cooked spinach (50 per cent. to 90 per cent. according to the general diet). Kreula and Virtanen[19] found considerable variation in the percentage absorption of carotene from finely grated raw and cooked carrots. This vital question of absorption undoubtedly needs further investigation.

Vitamin B_1.—The earlier study of the effect of cooking on vitamin B_1 was complicated by the publication of data obtained by unreliable methods. From recent results it would appear that vitamin B_1 is fairly stable towards the usual methods of household cooking, but insufficient work has yet been published for a definite conclusion to be given. Owing, however, to the solubility of the vitamin in water, extraction readily takes place into the cooking water, and the B_1 potency of the cooked vegetable may, therefore, be significantly less than that of the raw tissue. From the results of Baker and Wright[20] retentions of very approximately 30 per cent. and 75 per cent. are shown by cauliflower and potato respectively. Aughey and Daniel[21] found about 70 per cent. of the B_1 content of snap beans retained on boiling, and 80 per cent. for peas. Rose and Phipard,[22] working with peas, found the B_1 of the cooked vegetable to be 74 per cent. of that of raw tissues.

In a private communication, Dr. Pyke has given results from experiments on leafy green and flower head vegetables. His figures show a mean loss on cooking of 23 per cent. (range 9 per cent. to 38 per cent.) of the original vitamin B_1 content.

The effect of varying conditions of cooking on the vitamin B_1 content of vegetables has not yet been studied in any detail. Aughey and Daniel,[21] however, found an increased destruction of vitamin B_1 when soda was used for retaining the colour in green vegetables, and therefore advised that this practice should not be used.

Vitamin C.—It may appear that a disproportionate amount of space is devoted to vitamin C in the present communication. There is, however, ample justification for this, since, although protein, fat, carbohydrate, mineral salts, and vitamins A, B, and D can be obtained from several different sources, cooked vegetables are probably the sole source of vitamin C for a large proportion of the population in the winter months during war time. Raw fruits, especially oranges and grape-fruit, have been practically unobtainable since 1940, and the supply of canned fruit and vegetables has been limited.[23] Under normal conditions a fair quantity of ascorbic acid may be contributed to the diet by jams such as black currant, and marmalades, but even this source has been restricted by rationing. To emphasize this point, nine laboratory workers were asked to keep a record of their diet for the week ending 6th April, 1941, and from their reports an approximate value for their daily intake of vitamin C was calculated. (Table II.) Cooked vegetables were found to supply about 70 per cent. of the total vitamin C. The

TABLE II

SURVEY OF VITAMIN C IN NINE NORMAL DIETS
31ST MARCH TO 6TH APRIL, 1941

	Intake of ascorbic acid				
		Supplied by cooked vegetables			
Test subject	Per week mg.	mg.	Per cent. of total intake	Daily range mg.	Daily mean mg.
1	109	60	55	0–30	11
2	80	57	71	0–27	10
3	93	75	81	8–28	8
4	150	140	93	8–36	16
5	142	52	37	4–42	15
6	53	37	70	0–18	6
7	216	153	71	9–43	38
8	143	110	77	7–55	12
9	164	143	87	2–53	23

mean daily intake was about 12 mg. a day, and it was only when cooked greens were included that the probable requirement of 30 mg. per day was reached. These figures can only be regarded as approximate, since no actual weighings of the foods were made, and no vitamin C determinations were carried out on the foods eaten. It is probable, however, that the figures are on the high rather than on the low side, since they were calculated from average results on vegetables freshly harvested (except root vegetables) and cooked under carefully controlled conditions in the laboratory at the same time as the test.

A more intensive survey of the probable intake of vitamin C in a war-time diet has been carried out by Harris and Olliver.[24] The daily intake of the vitamin of 36 boys in a residential home was assessed by calculation with check analysis over a period of 12 weeks in the summer of 1941 and for the full 12 months of 1942. It was found that, apart from potatoes, important because of their regular use and the relatively large amounts consumed, the principal source of vitamin C throughout the year was green vegetables, such as cabbages and sprouts.

The distribution of vitamin C in foods has probably been more widely studied than that of any other vitamin, and the published literature on the effect of cooking on vitamin C is extensive. Unfortunately, the variation in the findings of different workers is very great, and, since results have often been published without full details of the conditions under which the sample has been cooked, the whole subject has become rather confused. It is important to know details such as time and rate of cooking, and ratio of water to vegetable used; otherwise false conclusions may be drawn. The time of boiling is especially important when American and English results are being compared, since Americans judge their vegetable cooked at a much earlier stage than does the English housewife. Sweeping conclusions have also been drawn from isolated tests, without consideration of the variation likely to occur even in carefully controlled laboratory conditions. In addition, the use of unreliable methods and faulty technique has produced misleading figures. Chemical methods, such as that devised by Harris, have been invaluable in investigating the effect of cooking on vitamin C, but many investigators have either used methods that cannot be regarded as accurate, or else have neglected the precautions stipulated for reliable tests. A striking example of this is the omission of an effective oxidation inhibitor such as metaphosphoric acid in the extraction of vegetable tissue (Musulin and King.[25]) Plant oxidases in the raw tissue rapidly oxidize ascorbic acid to dehydroascorbic acid, which will not reduce the 2 : 6 dichlorophenolindophenol dye ; if such oxidation is not prevented a fictitiously low value will be obtained. Another source of error is the failure to appreciate the great variation in the vitamin C content of raw vegetables. In kale, for instance, the average value for leaves is 50 per cent. higher than that for the young edible stems, yet a mixture of leaves and stems in varying proportions may be included in the materials for cooking. In all previously unpublished experiments to be described here, not less than four representative samples of the raw tissue were taken for each tests. Incomplete extraction from tough plant tissue, as compared with ready extraction from softened cooked tissue, is another fault in technique that may give rise to inaccurate conclusions.

Some or all of the above sources of error have probably contributed to the apparent increase in cooking noted by several workers (McHenry and Graham,[26], Reedman and McHenry,[27] Ahmad,[28] Levy.[29]) McHenry and his co-workers believe that this is due to the presence of an ester of ascorbic acid from which the free acid is liberated on cooking, and this has been supported by Guha and Pal,[30] Guha and Sen Gupta,[31] Scarborough and Stewart,[32] and other workers. No confirmation of this theory could be found by Mack and Tressler,[33] Bessey[34] and others, and more recent work by Harris and Olliver[35] would seem to show that the apparent gain is essentially due to faulty technique.

It is impossible to discuss or even to refer to all published work on the effect of cooking on vitamin C in vegetables, and it is, therefore, proposed here to consider some experimental results (mostly unpublished) carried out by the author and to compare the conclusions drawn from this work with those of some of the many other investigators. All the estimations of ascorbic acid in the experiments to be described were carried out by the 2 : 6 dichlorophenolindophenol method according to Harris and Olliver.[35] This method has been repeatedly checked by biological tests and is now accepted as a reliable means of assessing the concentration of ascorbic acid in plant tissue.

METHODS OF COOKING USED

Boiling.—Green vegetables, after the usual preparations, were placed in boiling salted water in an uncovered enamel saucepan. Head vegetables such as cabbage and cauliflower were quartered before cooking. Root vegetables, unless otherwise stated, were peeled and halved, or quartered if large. They were placed in cold

TABLE III

Effect of cooking on ascorbic acid content of green vegetables

Vegetable	Details of experiment	Investigators	Reference	Ascorbic acid in vegetable Per cent. Destroyed	Per cent. Lost	Per cent. Extracted	Per cent. Retained
Method of Cooking—Boiling							
Beans, Snap	17 mins. cook	Mack, Tapley and King	41	12	—	26	62
	19 mins. cook	Mack, Tapley and King	41	2	—	32	66
,, Lima	Frosted pack—17 mins. cook	McIntosh and Tressler	42	7	—	31	62
,, Runner	Stringed and sliced	Lampitt, Baker and Parkinson	43	22	—	33	44
Cabbage	Quartered, 18 mins. cook	Wellington and Tressler	36	16	—	56	38
	Quartered, 30–40 mins. cook	Lintzel, Hoffmann and Gores	37	14	—	26	60
		Levy	38	—	>50	—	>50
,, Spring	Quartered	Lampitt, Baker and Parkinson	43	23	—	37	40
Cauliflower	30–40 mins. cook	Lintzel, Hoffmann and Gores	37	—	27	—	73
,,	Quartered	Lampitt, Baker and Parkinson	43	8	—	36	56
Kale	Chopped, 25 mins. cook	Scheunert and Reschke	39	—	77	—	23
Peas	Frosted pack— 2 mins. cook	McIntosh and Tressler	42	12	—	18	70
	8 mins. cook	Fenton and Tressler	44	5	—	36	59
	16 mins. cook	McIntosh and Tressler	42	10 7	— —	48 40	42 53
,,	Market purchased	Lampitt, Baker and Parkinson	43	4	—	34	62
Spinach	Frosted pack—3 mins. cook	McIntosh and Tressler	42	4	—	26	70
	30–40 mins. cook	Lintzel, Hoffmann and Gores	37	38	—	24	38
Sprouts, Brussels	30–40 mins. cook	Lintzel, Hoffmann and Gores	37	2	—	54	44
	15 mins. cook	Scheunert and Reschke	39	—	47	—	53
,,	Trimmed, but uncut	Lampitt, Baker and Parkinson	43	0	—	35	65
Swiss Chard	10 mins. cook	Fenton, Tressler, Camp and King	40	14	—	44	42
Method of Cooking—Steaming							
Cabbage	Quartered, 25 mins. cook	Wellington and Tressler	36	—	42	—	58
,, Winter & Savoy	Quartered	Lampitt, Baker and Parkinson	43	30	—	6	65
Spinach		Dunker and Fellers	47	—	22	—	78
		Bernstein and Jakovleva	46	—	12	—	88
	Frosted pack, 10 mins. cook	McIntosh and Tressler	42	—	27 29	— —	73 71
Sprouts, Brussels	15 mins. cook	Scheunert and Reschke	45	—	29	—	71

salted water in a covered enamel saucepan and brought rapidly to the boil. The volumes of water and weights of vegetables were determined before cooking and after draining at the end of the experiment. All experiments were carried out on a household scale, i.e., sufficient material was taken for an average family of three or four. The ratio of volume of water to weight of vegetable may, of course, widely differ from these proportions when cooking is carried out on a large scale as in communal feeding, and under such conditions some adjustment of the results obtained in the present investigation may be necessary.

Steaming.—Vegetables were trimmed and cut before steaming exactly as for boiling, and were placed in an aluminium steamer fitted on to a saucepan containing boiling water. The steamer had a flat bottom perforated with holes approximately $\frac{1}{4}$-in. diameter. This type was found to be most effective in heating the vegetable rapidly —a point which seems to be of some importance. The weight of vegetables was checked before and after steaming.

Baking.—This method was only applied to potatoes, which were scrubbed and placed unpeeled in a moderate over for 2 hours.

Frying.—Only potatoes were fried in the experiments to be described. They were peeled and chipped and then placed in deep fat heated to blue smoking temperature.

RESULTS OF EXPERIMENTS

Green vegetables (leafy vegetables, peas and cauliflower).—The instability of vitamin C in plant tissue has been much exaggerated in the past. A survey of some of the recent work (see Table III) shows that the actual destruction of ascorbic acid when green vegetables are boiled is usually small, but that the loss to the consumer by extraction of the vitamins into the cooking water may be considerable. (See also Olliver.[48]) This is confirmed by the present work (Table IV) which shows an average destruction of only 9 per cent. out of a total of 21 tests, whilst the average loss by extraction is 61 per cent. Destruction of the vitamin up to 30 per cent. may be found on cooking some varieties of cabbage but invariably extraction is the greater. It is possible that this variation in destruction may be linked with the amount of oxidases present in different samples, with the rate of inactivation of the oxidases, or with the metallic constituents of vegetable tissue. For all practical purposes, however, the loss of vitamin C due to destruction, when green vegetables are boiled, is small. The loss due to leach, however, is a serious problem. With kale about 75 per cent. of the total is

TABLE IV

Effect of boiling on the ascorbic acid content of green vegetables

Vegetable	Time of boiling	Vol. of water used to weight of vegetable*	Ascorbic acid in vegetable			Approximate amount of ascorbic acid in 4 oz. of cooked vegetable (mg.)†
			Per cent. Destroyed	Per cent. Extracted	Per cent. Retained	
Cabbage (quartered)	30 mins.	4 : 1	7	62	31	33
		4 : 1	2	62	36	38
		5 : 1	4	61	35	37
		9 : 1	7	69	24	26
		11 : 1	19	66	15	16
		13 : 1	18	53	29	31
		14 : 1	8	66	26	28
Cauliflower head (quartered)	20 mins.	4 : 1	2	65	33	24
		3 : 1	4	57	39	28
Kale	20 mins.	9 : 1	17	71	12	17
	30 mins.	5 : 1	8	67	25	35
		5 : 1	19	46	35	49
		9 : 1	6	77	17	24
		9 : 1	10	76	14	20
		9 : 1	8	78	14	20
		12 : 1	2	84	14	20
Peas, Green	25 mins.	3 : 1	12	51	37	16
		3 : 1	9	49	42	18
Sprouts, Brussels	20 mins.	3 : 1	13	34	53	73
		4 : 1	3	48	49	68
		7 : 1	7	44	49	68

* The ratio of water to vegetable normally used in domestic practice was about nine to one for cabbage or kale, and about four to one for Brussels sprouts.

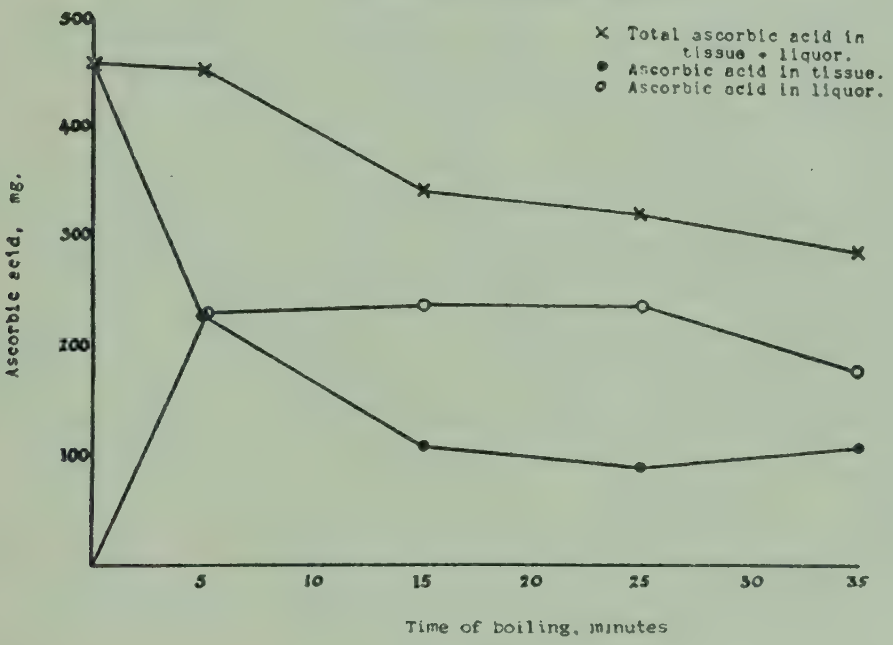
† Based on average results obtained for freshly harvested vegetables.

extracted into the cooking water, about 45 per cent. to 65 per cent. with cabbage, 40 per cent. with cauliflower, and 40 per cent. to 50 per cent. with sprouts and peas. It is interesting to see how the structure of the vegetable seems to have some bearing on the degree of extraction—the loss being greatest with a loosely packed leaf vegetable and smallest with the tightly packed bud and starchy seed.

In Fig 1 the rate at which ascorbic acid is leached from kale during boiling is shown, and it is seen that almost all the extraction takes place within the first 5 minutes of boiling. The destruction of ascorbic acid in this test is greater than is usually found. In all probability this is due to increased oxidation, caused by the removal and straining of the vegetable at frequent intervals for weight determined throughout the test.

Fig. 1

Ascorbic acid in boiled kale



The wastage of vitamin C resulting from discarding the strained vegetable water is apparent and figures in Table IV show that, whilst 20 mg. of ascorbic acid can be obtained from 4 oz. of cooked vegetable, over 100 mg. may be strained away from that quantity. It is unfortunate that vegetable cooking water is so greatly despised by the English housewife, since it can be used as a very satisfactory stock for soups. Green vegetables are usually rich in ascorbic acid and, therefore, even allowing for loss in the cooking liquor, sufficient vitamin C to supply a daily requirement of 30 mg. would probably be obtained from a serving of 4 oz. (about 2 tablespoonfuls) ; 4 oz. of sprouts, if carefully cooked, may provide as much as 73 mg. of ascorbic acid.* Green peas and stringless beans contain much less ascorbic acid in the raw tissue than do the green leafy vegetables, and the cooked vegetable is a correspondingly poorer antiscorbutic.

The conditions which may be varied by the housewife in boiling green vegetables are numerous, but one of the more common variations is in the amount of water used for a weight of vegetable. It is usual to advocate "enough water to cover the greens," but this recommended amount will necessarily depend upon the size of the saucepan and upon the packing of the vegetables. Results obtained for kale (Table IV) suggest that the use of a small volume of liquid causes greater rentention of ascorbic acid in the tissue than does a large volume, but this difference is not significant in the other vegetables examined. It is possible that the difference in the amount of ascorbic acid retained becomes significant when the volume of water used is smaller than any taken for these tests, but such small volumes of water would be impracticable for the boiling of quartered cabbage. Cooking shredded cabbage in a minimum of water ensures maximum retention of ascorbic acid; Pyke[53] points out that holding the cabbage between shredding and cooking should be avoided. Reference should be made to the work of Allen and Mapson[49] for details on the extraction of ascorbic acid from green vegetables as affected by the volume of the water and by the rate of boiling.

The effect on the loss of vitamin C from green vegetables when the rate of boiling is varied has also been studied by Delf[50] who found that a short rapid boiling was preferable to a long simmering. Floyd and Fraps[51] obtained a rather greater loss on simmering than on boiling, although the difference between their values cannot be regarded as significant from a nutritional standpoint. The figures in Table V suggest that simmering may result in a greater extraction of ascorbic acid than does rapid boiling and this is especially noticeable when a fair quantity of the vitamin is normally retained. In this connection it should be emphasized that the normal method of cooking greens, i.e., by plunging into boiling water, should always be used. If green vegetables are put into cold water and then brought to the boil, the loss is, of course, great.

The use of soda was at one time decried, and Floyd and Fraps[51] found an increased loss of vitamin C for boiled vegetables when sodium carbonate was added to the cooking water. They used distilled water, however, in their control tests. Using tap water, Olliver[52] was unable to find any real difference in the retention of ascorbic acid in cabbage and sprouts boiled with and without the addition of normally small amounts of soda. It should be noted, however, that addition of sodium carbonate may be important if the food is subsequently kept hot, as it appears to accelerate the normal loss.[53]

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* These figures are obtained from freshly harvested and carefully cooked vegetables. See Tables III, IV, V, VI and Figs. 1, 2 and 3.

TABLE V

EFFECT OF RATE OF BOILING ON RETENTION OF ASCORBIC ACID IN BOILED GREEN VEGETABLES

Vegetable	Details of cooking	Ascorbic acid in cooked vegetable Per cent. Destroyed	Per cent. Extracted	Per cent. Retained
Cabbage	Normal rate of boiling for 20 mins.	4	61	35
	Simmering for 30 mins.	8	70	22
Kale	Normal rate of boiling for 30 mins.	6	77	17
	Simmering for 40 mins.	Nil	81	19
Sprouts, Brussels	Normal rate of boiling for 20 mins.	3	48	49
	Simmering for 30 mins.	5	59	36

Høygaard and Rasmussen,[54] referring to the inhibiting effect of sodium chloride on the oxidation of ascorbic acid found by Kellie and Zilva,[55] suggested that vegetables cooked in water containing sodium chloride retained their ascorbic acid better than when cooked without salt. They also used distilled water controls, and their published results hardly justify their conclusions. In the present tests (Table VI) addition of salt was not found to have any significant effect on the loss of ascorbic acid from boiled green vegetables.

TABLE VI

EFFECT OF ADDITION OF SALT ON RETENTION OF ASCORBIC ACID IN BOILED GREEN VEGETABLES

Vegetable	Details of cooking	Ascorbic acid in cooked vegetable Per cent. Destroyed	Per cent. Extracted	Per cent. Retained
Cabbage	Boiling in salted water for 20 mins.	7	69	24
	Boiling in unsalted water for 20 mins.	2	80	18
Kale	Boiling in salted water for 30 mins.	6	77	17
	Boiling in unsalted water for 30 mins.	4	81	15
	Boiling in salted water for 30 mins.	10	76	14
	Boiling in unsalted water for 30 mins.	8	78	14
	Boiling in unsalted water for 30 mins.	9	78	13

Salt used = approximately 3 g. to 1 pt. of water.

The effect of steaming on green vegetables as compared with the effect of boiling is very striking (see Tables III and VII). A high percentage of ascorbic acid is retained and the retention is indeed as great as the extraction found in boiling. The practical significance of this is apparent, since a 4 oz. portion of freshly harvested and carefully-steamed green vegetables may provide two or three times the normal daily requirement of vitamin C (taken as 30 mg.).

TABLE VII

EFFECT OF STEAMING ON ASCORBIC ACID CONTENT OF GREEN VEGETABLES

Vegetable	Details of cooking	Per cent. Lost	Per cent. Retained	Approximate amount of ascorbic acid (mg.) in 4 oz. of cooked vegetable*
Cabbage	Normal steaming, 30 mins.	48	52	56
	Vegetables placed in steamer 2 mins. before water boiled. Cooked 30 mins.	65	35	37
Kale	Normal steaming, 30 mins.	33	67	94
		39	61	85
		34	66	92
		37	63	88
	Normal steaming, 35 mins.	54	46	64
	Vegetables placed in steamer 2 mins. before water boiled. Cooked 30 mins.	52	48	67
	Vegetables steamed 50 mins. in colander used as improvised steamer	60	40	56
Sprouts, Brussels	Normal steaming, 20 mins.	40	60	84
	Vegetables placed in steamer 2 mins. before water boiled. Cooked 20 mins.	36	64	90

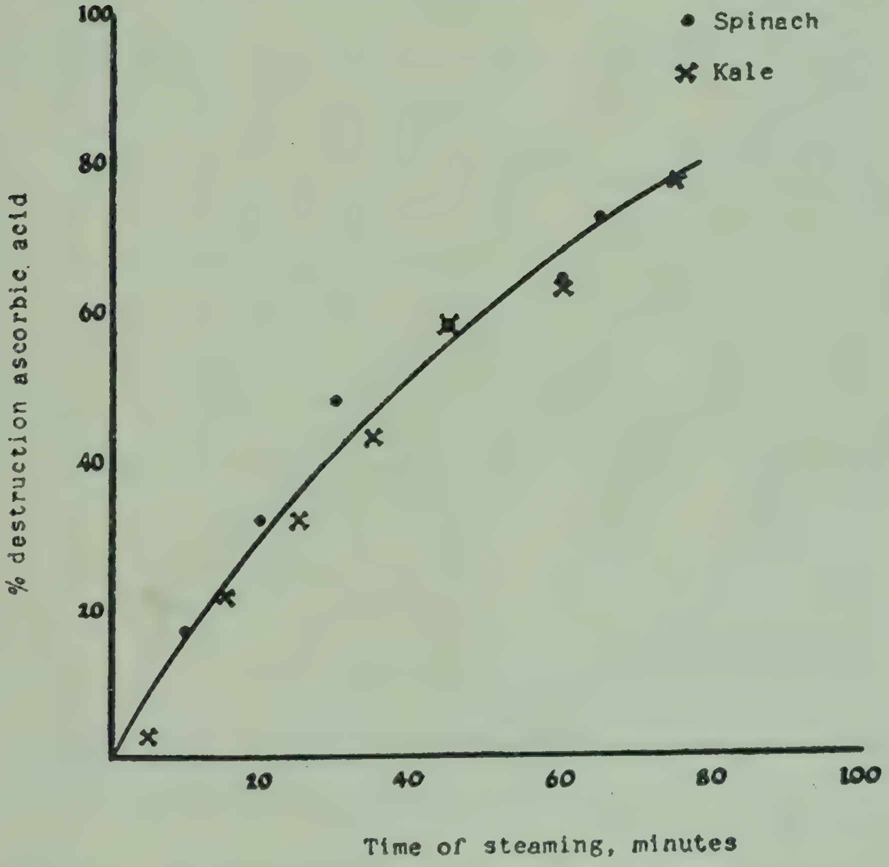
* Based on average results obtained from freshly harvested vegetable.

An important point noted with kale and cabbage (but not with sprouts), was that, if the steamer water was allowed to go off the boil and then brought to the boil 2 minutes after the addition of the kale to the steamer, a greatly increased loss of ascorbic acid was found. It is probable that the enzymes are activated at this stage before sufficient heat is transmitted to the tissue for their destruction. When a colander was used as an improvised steamer—a practice often met with in private houses when steamers are not available—there was again an increased destruction. This was probably due to the time factor, since the kale took longer to cook by this method than when the correct steamer was used.

The loss of ascorbic acid in steamed green vegetables is progressive with time (Fig. 2) and the rate of destruction is considerable. Therefore, although green vegetables, steamed until they are just cooked, retain much more vitamin C than do boiled green vegetables, over-cooking is to be rigorously avoided. Keeping hot, which as carried out in private households and institutions is usually merely an extension of steaming, has a similar effect (Scheunert and Reschke[39]). The results shown in Fig. 3 were obtained in a test in which the cooked vegetable was kept warm on a covered plate over a saucepan of boiling water; the rapid destruction of the vitamin under these conditions emphasizes the need for avoiding this practice.

Fig. 2

Ascorbic Acid in Steamed Green Vegetables



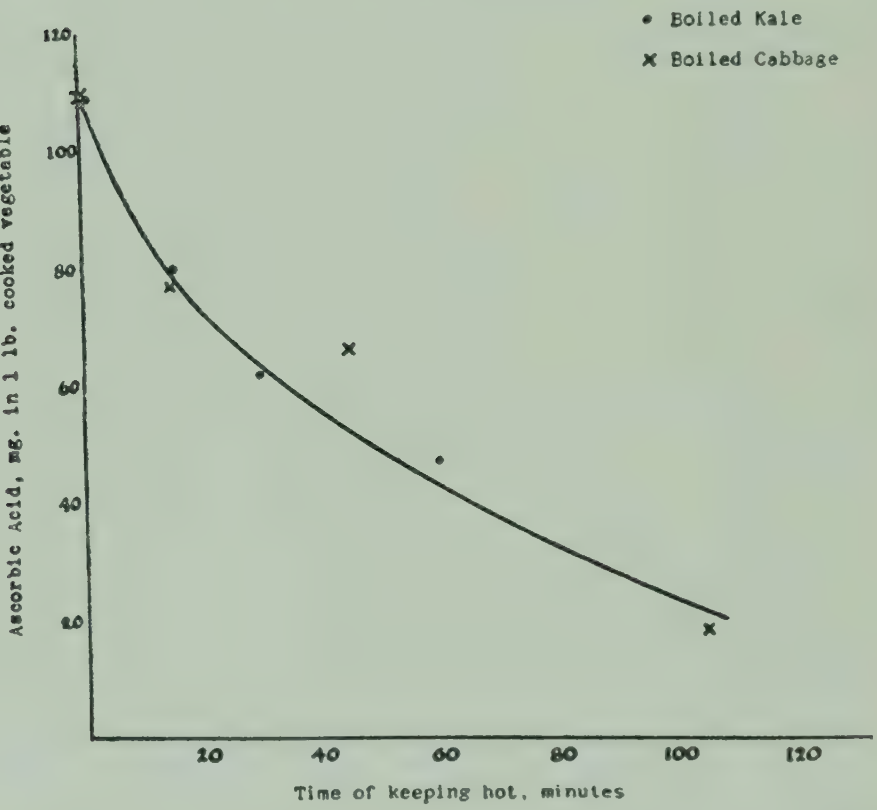
The apparent advantages of steaming over boiling as applied to green vegetables may be outweighed by the factors here discussed. Unless an efficient steamer is used, and unless the water is rapidly boiling when the vegetable is added, there may be no real advantage in steaming as opposed to boiling. In addition, there is the temptation for the housewife to continue the steaming of the vegetables long after they are cooked, with consequently an even more rapid destruction of ascorbic acid than in boiling. Combined with these factors, the difficulty of retaining the green colour of the tissues on steaming must be regarded as a major disadvantage from the practical point of view.

Root vegetables.—The morphological differences between root and leaf tissue lead one to expect differences in the effect of cooking on the two main classes of vegetables. Experimental results have confirmed this, and one of the most striking conclusions is the significantly higher percentage of ascorbic acid retained in boiled roots than in boiled green vegetables (Table VIII). About 60 per cent. of the vitamin remains in root tissue after boiling, or about double the percentage usually found with leaves. Published results (Table IX) dealing with boiled root vegetables rarely differentiate between loss of ascorbic acid due to extraction and to destruction. From Table VIII, however, it is seen that, although there is some considerable variation in the findings, the amount of vitamin C usually destroyed is as great as, if not greater than, the amount leached into the cooking liquor. It is possible that this is connected with the rate of heat penetration. In the starchy thick tissue of a

Fig. 3

BOILED GREEN VEGETABLES

Effect of keeping hot on ascorbic acid content



piece of potato, heat penetration is slow, and, whilst temperature conditions for oxidase action are favourable, extraction of soluble constituents of the cells into the cooking water is inhibited. In the thin, loosely packed tissue of a leaf, heat penetration is rapid and oxidases are rapidly destroyed, but soluble constituents are easily extracted.

Pies and Schroeder[63] and others[64,38] found only a very small loss of ascorbic acid in potatoes boiled unpeeled. The experiments of Lieck[65] and also of Lyons and Fellers[59] showed peeled potatoes to retain a percentage of the vitamin similar to the unpeeled tubers; our own findings confirm this (Table IX). Loss by extraction tends to be slightly lower in the unpeeled than in the peeled potatoes and it is probable that a negligible amount of ascorbic acid is extracted before the skins burst. The actual destruction seems unaffected, however, by the presence or absence of skins, and since destruction is the major factor, the retention of ascorbic acid in peeled and unpeeled boiled potatoes is similar.

It must be remembered, however, that the skins can be peeled cleanly off after boiling, and therefore the tissue normally lost by peeling before cooking, and containing approximately 15 per cent. of the total ascorbic acid (see below), is saved.

Variation in the volume of water used for boiling a given weight of root vegetables does not appear to affect the percentage retention of ascorbic acid (Table IX). When old stored potatoes of initially low anti-scorbutic value were boiled in a large volume of water it was impossible to determine with certainty the amount of ascorbic acid in the liquor. Consequently it was not possible to differentiate exactly between the loss of ascorbic acid due to destruction and that due to extraction. The percentage of ascorbic acid retained, however, even in such instances, was found to be uninfluenced by variations in the volume of water.

It is customary for old root vegetables to be boiled from cold water, but the effect of boiling from hot water was considered. The retention of ascorbic acid did not appear to be affected by the initial temperature of the water used. Boiling potatoes was carried out in salted and in unsalted water, but the differences were, for all practical purposes, again found to be negligible (Table X).

With leafy vegetables steaming and boiling have been found to have widely differing effects on the ascorbic acid content of the cooked tissue. This difference is not so marked with root vegetables, and the percentages of the vitamin retained in steamed potatoes are, on an average, only very slightly higher than those retained in

TABLE VIII

Effect of boiling on the ascorbic acid content of root vegetables

Vegetable	Time of boiling	Vol. of water used to weight of vegetable	Ascorbic acid in vegetable				Approximate amount of ascorbic acid in 4 oz. of cooked vegetable (mg.)
			Per cent. Destroyed	Per cent. Lost	Per cent. Extracted	Per cent. Retained	
Potato—Peeled and halved—							
Lifted and clamped, 1 month ..	20 mins.	3 : 1	15	—	16	69	15
Lifted and clamped, 5 months ..	15 ,, ...	2 : 1	21	—	19	60	6
		2 : 1	34	—	18	48	4
	20 ,, ...	2 : 1	15	—	30	55	5
		3 : 1	16	—	24	60	6
		4 : 1	18	—	14	68	6
		9 : 1	—	37	—	63	6
		14 : 1	—	29	—	71	6
	Boiled from hot water	3 : 1	28	—	19	53	5
	20 mins.	9 : 1	—	40	—	60	6
Potato—Unpeeled and uncut—							
Lifted and clamped, 1 month ..	35 ,, ...	2 : 1	41	—	13	46	10
	45 ,, ...	2 : 1	35	—	10	55	13
Lifted and clamped, 5 months ..	20 ,, ...	5 : 1	—	41	—	59	5
	25 ,, ...	2 : 1	—	33	—	67	6
Parsnip—Peeled and quartered—							
Stored 4 weeks	30 ,, ...	5 : 1	—	50	—	50	3
Swede—Peeled and quartered—							
Stored through winter	45 ,, ...	15 : 1	16	—	30	54	26

TABLE IX

EFFECT OF COOKING ON ASCORBIC ACID CONTENT OF ROOT VEGETABLES

Vegetable	Details of experiment	Investigators	Reference	Ascorbic acid in vegetable			
				Per cent. Destroyed	Per cent. Lost	Per cent. Extracted	Per cent. Retained
Potato	Boiled peeled, cook 26 mins.	Halliday and Noble	56	—	52	—	48
		Wachholder	57	—	>25	—	<75
		Scheunert, Reschke and Kohlemann	58	—	29–38	—	62–71
		Lyons and Fellers	59	—	49	—	51
	cook 35 mins.	Richardson and Mayfield	60	—	Nil	—	100
	Boiled peeled	Lampitt, Baker and Parkinson	43	7	—	15	79
	Boiled unpeeled	Levy	38	—	1–20	—	80–99
		Lyons and Fellers	59	—	40	—	60
		Wachholder	57	—	<10	—	>90
	Steamed peeled	Levy	38	—	20–25	—	75–80
		Scheunert	58	—	24–30	—	70–76
	Steamed unpeeled	Levy	38	—	15	—	85
		Wachholder	57	—	Slight	—	83
	20 mins.	Scheunert, Reschke and Kohlemann	58	—	17	—	83
	Baked	Levy	38	—	20–45	—	55–80
		Lyons and Fellers	59	—	40	—	60
	Fried, 20 mins.	Levy	38	—	55–80	—	20–45
		Richardson, Davis and Mayfield	60	—	33	—	67
Parsnips	Boiled peeled and sliced	Mayfield and Richardson	61	—	36	—	64
	Boiled unpeeled	Mayfield and Richardson	61	—	13	—	87
Turnips	Boiled, ½-in. cubes	Lampitt, Baker and Parkinson	43	2	—	43	55
Carrots	Boiled, 15 mins.	Fenton, Tressler, Camp and King	62	—	44	—	56
	Steamed, 20 mins.	Fenton, Tressler, Camp and King	62	—	14	—	86

boiled potatoes (Table XI). This may be due to the extended time necessary to cook potatoes by steaming. It is probable that the loss on steaming is caused primarily, if not entirely, by destruction and not by extraction, since the losses in peeled and unpeeled tubers are comparable. The only advantage in using potatoes unpeeled would therefore seem to lie in the saving of the 15 per cent. ascorbic acid by the "clean" peeling after cooking, already mentioned. One disadvantage may tend to offset this. The housewife usually allows a rather longer time for steaming unpeeled than peeled potatoes. The loss of ascorbic acid on steaming root vegetables is progressive with time (this is indicated in Table XI) and consequently, as was found with green vegetables, extended steaming will cause increased

TABLE X

EFFECT OF ADDITION OF SALT ON RETENTION OF ASCORBIC ACID IN BOILED PEELED ROOT VEGETABLES

Vegetable	Details of cooking	Ascorbic acid in cooked vegetable Per cent. Destroyed	Per cent. Extracted	Per cent. Retained
Potato ..	Boiling in salted water for 20 mins.	15	30	55
	Boiling in unsalted water for 20 mins.	8	31	61
	Boiling in salted water for 20 mins.	16	24	60
	Boiling in unsalted water for 20 mins.	31	26	43
Parsnip ..	Boiling in salted water for 30 mins.	9	41	50
	Boiling in unsalted water for 30 mins.	3	46	51

Salt used = approximately 3 g. to 1 pt. of water.

TABLE XI

EFFECT OF STEAMING ON THE ASCORBIC ACID CONTENT OF ROOT VEGETABLES

Vegetable	Time of steaming	Ascorbic acid in vegetable Per cent. Lost	Per cent. Retained	Approximate amount of ascorbic acid (mg.) in 4 oz. cooked vegetable
Potato—Peeled and halved—				
Lifted and clamped 1 month ..	35 mins.	26	74	17
	45 ,,	47	53	12
Lifted and clamped 5 months ..	30 ,,	18	82	7
	25 ,,	27	73	6
	30 ,,	33	67	6
Potato—Unpeeled and uncut—				
Lifted and clamped 1 month ..	50 mins.	44	56	13
	45 ,,	38	62	14
Lifted and clamped 5 months ..	30 ,,	23	77	7
	35 ,,	31	69	6
	35 ,,	35	65	6
Parsnip—Peeled and quartered—				
Stored 4 weeks	40 mins.	58	42	3
	45 ,,	56	44	3

loss of the vitamin. Keeping hot will still further reduce the antiscorbutic value of the vegetable, and cooked old potatoes, with an initial value of 3·6 mg. of ascorbic acid per 100 gm., had fallen in value to only 1·6 mg. per 100 g. after being kept hot for 25 minutes. In cooked potatoes the loss is greater if the vegetables are mashed and then kept hot than if they are retained whole under similar conditions.[66]

A surprisingly good retention of ascorbic acid was found in potatoes cooked by dry methods (Table XII). Potatoes baked in their jackets in some cases retained 80 per cent. of their total ascorbic acid. Owing to loss of water during the cooking, the apparent retention was, in some instances, found to be 100 per cent. One interesting point noted was that more ascorbic acid appeared to be destroyed in the larger than in the small potatoes. This again may be connected with the question of heat penetration, but sufficient experiments were not carried out to justify the drawing of definite conclusions. Frying potatoes in deep fat also resulted in a good retention of the vitamin. An apparent gain in ascorbic acid may even be obtained. This is partly due to the high percentage of water which is lost during boiling but may also be explained by the production of reducing substances other than ascorbic acid which affect the indophenol titration.[67] In the results given in Table XII no correction has been made for fat absorption.

TABLE XII

EFFECT OF DRY METHODS OF COOKING ON ASCORBIC ACID CONTENT OF POTATOES

	Ascorbic acid in vegetable			
	Per cent. destroyed		Per cent. retained	
Method of cooking	Apparent	Real*	Apparent	Real*
Baking, unpeeled. Individual potatoes.	33	55	67	45
	23	43	77	57
	30	—	70	—
Baking, unpeeled. Individual potatoes (large)	51	59	49	41
(medium)	23	36	77	64
(small)	Nil	22	100	78
Baking, unpeeled. Representative sample	1	19	99	81
Frying in deep fat—15 mins. ..	6 (Gain)	28	106	72

* i.e., corrected for moisture loss.

Discussion of vitamin C results.—Although much work still remains to be carried out on the effect of cooking on the vitamin C content of vegetables, a few more or less definite conclusions can be drawn from the results discussed in this communication. It is proposed to apply these points and conclusions from work on the other aspects of the nutritional value of vegetables and to suggest some guiding principles for the cooking of vegetables.

Before doing so, however, there is one particular aspect of vitamin C in vegetables which requires emphasis. The loss of ascorbic acid on cooking is, in nearly all instances, of small practical importance compared with the variation in antiscorbutic value of the raw material.[68] Thus a freshly harvested green leaf vegetable, after boiling, may only retain 14 per cent. of its initial ascorbic acid content. Yet a 4 oz. helping will provide 20 mg. of ascorbic acid (Table III) compared with 6 mg. from a 4 oz. helping of old potatoes that has retained 71 per cent. of its vitamin C potency on cooking (Table VIII). The variation in the antiscorbutic value of the raw material cannot, of course, altogether be avoided. Even allowing for varietal influence, it is unlikely that a potato, for instance, will be produced with as high a vitamin C value as is usual for a cabbage.

One factor influencing the raw material can, however, be to some extent controlled, and that is storage effect. This factor is especially important with root vegetables, such as potatoes, which are commonly stored for spring use. It has been shown by several workers,[48,69,70], that freshly dug potatoes are valuable antiscorbutics, but that, after storage through the winter, the content of ascorbic acid in these vegetables has fallen considerably.

In Table XIII the results of over 100 tests on potatoes are given, to show the striking differences in antiscorbutic value between the freshly dug and the stored tubers. The antiscorbutic values which may be expected from freshly boiled potatoes at different periods of the year are given in Table XIV.

TABLE XIII

EFFECT OF STORAGE ON THE ASCORBIC ACID CONTENT OF POTATOES

Variety	Dates of test	Details	Mg. ascorbic acid per 100 g. Average value	Mg. ascorbic acid per 100 g. Range of values
Eclipse	July–August	Freshly dug	35	28–39
	January–February	Clamped*	9	7–12
King Edward	August	Freshly dug	30	27–39
	December	Clamped*	14	11–17

* Clamped in October when the average value was then similar to August testing.

Green vegetables are not usually stored for any extensive periods, but, since the rate of destruction of ascorbic acid is much more rapid in these than is found with root vegetables, normal storage at room temperature may have some considerable influence. Chappell[71] concludes that market-purchased foods contain satisfactory amounts of ascorbic acids when purchased. Comparing, however, her mean values for vegetables with those for freshly harvested materials, one finds that generally the shop-purchased vegetables have only about half the antiscorbutic value of the fresh (Table XV). This is a serious consideration when a further probable loss on storage in the household, combined with a loss on cooking, has to be taken into reckoning.

TABLE XIV

Average ascorbic acid content of cooked potatoes at different periods of the year

Month	Mg. of ascorbic acid per 100 g.
August September*	16
October	12
November	9
December	7
January	5
February	3
March and onwards	2

* Assuming that potates are freshly dug in these months.

TABLE XV

Comparison of ascorbic acid values of fresh and shop purchased vegetables

	Mg. ascorbic acid per 100 g.				
	Average value for freshly harvested material (Olliver)	Mean value for shop purchased material (Chappell)		Value of shop purchased material expressed as per cent. of fresh material	
Vegetable		Cheap market	Expensive market	Cheap market	Expensive market
Beans, French	11	6·95	4·7	63	43
Cabbage	94	114·6	34·8	122	37
Carrot	4	2·5	5·15	62	129
Cauliflower	73	35·6	73·2	49	100
Kale	123	42·7	65·3	35	53
Pea, green	30	10·44	13·9	35	46
Potatoes, new	30	11·9	11·4	40	38
Sprouts, Brussels	122	61·4	69·2	50	57

3. Retention of Maximum Nutritional Value in Cooking Vegetables

To summarize, from the effect of cooking on the various nutritional constituents of vegetables the following guiding principles for the housewife can be indicated:

(1) Vegetables should be used as soon as is practicable after harvesting.

(2) Waste in preparation of vegetables should be reduced to a minimum and, with green vegetables, only tough stems and

badly wilted leaves should be removed. Root vegetables can be cooked either very thinly peeled or unpeeled.

(3) Green vegetables should be boiled rapidly for the shortest possible time in the minimum amount of water. The cooking liquor should be used for soups and gravies.

(4) Root vegetables can be boiled, steamed, baked, or fried, but the need for avoiding excess cooking applies as to green vegetables.

(5) "Keeping hot" of cooked green or root vegetables should be most rigorously avoided. This is probably the most important of all the factors considered.

(6) The addition of salt is to be advised in the cooking of vegetables, since it improves the palatability of the tissue and does not increase the loss of nutritive value.

(7) The use of normally small amounts of soda for keeping the green colour of leafy vegetables cannot be condemned until the practical effects on vitamin B_1 destruction have been more fully investigated. It should, however, be recommended that soda is not used if the vegetables are subsequently to be kept hot.

In conclusion, it should be stressed that it is not always possible to judge the nutritional value of a foodstuff from its chemical analysis. Questions of palatability and of digestion and absorption must also be taken into consideration. The effect of cooking on the digestibility of vegetables and on the absorption of the nutrient constituents of vegetables has been given too little study in the past. It is to be hoped that this aspect of vegetables as a food will receive more attention, so that the nutritional value of cooked vegetables can then be more fully assessed.

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CHAPTER XII

THE EFFECT OF CANNING ON THE NUTRITIVE VALUE OF VEGETABLES

By W. B. Adam

The consumption of canned vegetables increased very rapidly during the fifteen years which preceded the present war; although no official figures are available of the annual output of canned vegetables in this country it may be estimated that the number of cans packed in 1924 probably did not exceed ten million, whereas the output in 1939 must have reached 300 to 400 million. As similar developments took place in other countries, scientific workers were prompted to study the nutritional problems which might arise as a result of substituting heat-sterilized for home-cooked foods. These investigations proceeded along two lines, one being concerned with the effect of canning on each of the major nutrients and the other with the effect of a complete diet of canned foods on health.

Loss of nutritive value of vegetables used for canning may take place at any or all of three stages in the journey from the fields through the cannery, to the dinner table. The first stage represent, the period between the picking or lifting of the vegetable and its arrival at the canning factory, the second includes all the canning operations, and the third covers subsequent storage of the cans and preparation of the vegetables for the table. The loss of nutritive value at the first of these stages is generally negligible, as most vegetables are transferred directly from the field to the cannery without any delay apart from the few hours which may be needed for the journey. In this respect the canner is better placed than the housewife, whose vegetables may have been gathered several days before they are cooked, but the canner is in no better position than the domestic purchaser when he has to handle clamped vegetables, such as potatoes which may have already lost much of their vitamin C. Losses of a more serious character occur during canning and subsequent storage, and these can best be considered broadly in relation to each of the main canning operations and more fully when the separate nutrients are discussed in detail.

Losses During Canning and Storage

When vegetables are prepared for canning there may be some wastage of non-edible material. This is negligible for dried legumes and comparatively slight for some root crops, but may be very considerable (up to 70 per cent.) for fresh peas. The amount of non-edible material removed in peeling, trimming, or podding is about the same in the cannery as in a well-regulated domestic kitchen, but the useful disposal of this waste is a problem much more easily solved in the canning factory than in the home. Normally the great bulk of waste material from vegetable canneries is stored as silage, returned to the land, or dried for use as cattle food.

Preliminary washing or steeping of root vegetables in cold water to remove adhering dirt produces a negligible loss of nutritive material, and the soaking of dried legumes for periods up to 24 hours results in a slight reduction of the soluble constituents—usually about 1 per cent. to 4 per cent. of the dry weight.

The operation most open to criticism is "blanching," in which the vegetables are heated in water for periods ranging from 2 to 20 minutes at 80° C. to 100° C. For most vegetables blanching is advisable, and for some essential; it acts as a cleansing operation, destroys enzymes, expels occluded gases, causes the vegetable to shrink, and sometimes improves the colour and flavour. Adam, Horner and Stanworth[1] have shown that the losses on blanching vegetables in water at 100° C. vary considerably with the material treated. Vegetables of large surface area in proportion to volume (such as peas, beans and diced roots) lose about 20 per cent. to 30 per cent. of sugars and mineral substances, 10 per cent. to 50 per cent. of vitamin C and 10 per cent. to 25 per cent. of protein when blanched for 3 minutes. The corresponding losses in the larger vegetables (such as whole roots and potatoes) are 10 per cent. to 20 per cent. of sugars and mineral substances, 10 per cent. to 35 per cent. of vitamin C and 5 per cent. to 10 per cent. of protein. Vegetables blanched in steam retain a higher proportion of their original nutritive value, but practical difficulties associated with steam blanching have so far precluded its general use in canneries. The effect of blanching on the vitamin B_1 content of vegetables has been studied recently by Clifcorn and Heberlein[2] who recorded the following losses: peas 5 per cent. to 24 per cent., cut green beans 17 per cent., whole green beans 6 per cent. and asparagus *nil*.

Processing vegetables at a temperature range of 116° C. to 127° C. has little effect on most of the nutrients, but there is some loss (generally about 20 per cent. to 40 per cent.) of vitamin B_1 and also a slight loss (about 5 per cent. to 15 per cent.) of vitamin C. Baked beans—which are processed for a longer time than most other vegetables—lose a higher proportion of B_1 at this stage.

The changes which occur on storage are partly physical and partly chemical. The latter are relatively slight, but the former consist mainly of the redistribution of the soluble constituents between the solid and liquid contents. Distribution losses may amount to 45 per cent. in the more loosely filled products, such as stringless beans, or about 30 per cent. in tightly filled cans of peas, carrots or beetroots. These losses need not occur if the liquid portion is used for making soup in the home, and do not occur in certain products—such as baked beans and spinach purée—where the entire contents are eaten together.

VITAMINS

Vitamin A.—This is absent from plants, but its percursor, carotene, is an important constituent of most green leafy vegetables and of some yellow root vegetables. Its low solubility in water and its high heat stability protect it against loss or destruction during blanching and processing. Investigations by Kohman,[3] Hanning,[4] Hoff,[5] Langley,[6] Crist,[7] Douglass[8] and their co-workers have shown that little or no loss of vitamin A activity occurs in the canning of peas, green string beans, carrots, asparagus and spinach.

Vitamin B_1.—This vitamin is not easily oxidized but is fairly readily destroyed, even in a slightly acid medium, when heated to temperatures above 100° C. Some loss may, therefore, be expected by leaching during blanching and by destruction during processing. Lunde, Kringstad, and Olsen[9] have shown that 25 per cent. of the B_1 in peas may be lost during blanching. Kohman[10] has admitted that some vitamin B_1 is lost in the canning of spinach and cabbage, but he considers that less destruction occurs in the canning of peas. Langley, Richardson and Andes[6] found that carrots canned in the autumn lost only a small percentage of their vitamin B_1, whereas similar carrots canned after storage until the spring showed a loss as high as 50 per cent. More recent investigation by Fellers,[11] Harris,[12] Farrell,[13] Clifcorn[2] and their co-workers have shown the following losses of B_1 to have occurred in the whole of the canning operations.

Vegetable	Loss of vitamin B_1 Per cent.
Asparagus	10, 18, 35 and 37
Beans (green), whole	17, 17 and 24
,, (green), cut	39
,, (wax)	40
,, (Lima)	40, 61, 68 and 72
Beetroot	8 and 31
Carrots	24 and 40
Peas	8, 23, 31, 41 and 50
Spinach	29, 56 and 82
Tomatoes	10, 11, 15 and 16

About 25 per cent. to 50 per cent. of the vitamin B_1 retained is in the liquid portion of the contents.

Vitamin B_2 complex.—Very few reliable figures have been published on the destruction of the various constituents of the B_2 complex, but their heat stability is generally greater than that of B_1 and it may be assumed that losses occur mainly through leaching. Fellers, Esselen and Fitzerald[11] found the losses of riboflavin during canning to be as follows: peas 0 per cent., asparagus 2 per cent., Lima beans 30 per cent., and spinach 55 per cent. When the solid contents only are considered, the total riboflavin remaining in the vegetables was 30 per cent. to 71 per cent. of that originally present. Farrill and Fellers[13] report a loss of 3 per cent. of riboflavin in the canneng of whole green beans.

Vitamin C.—More attention has been given to this vitamin than to any other nutrient present in canned vegetables. It is readily soluble and hence may be lost by leaching during blanching; it may also be destroyed at various stages throughout the canning operations, starting with the period between preparation of the vegetable and the first heat treatment. This period is generally short and the risk of loss is slight if ascorbic acid oxidase is not present or the tissues are undamaged. Horner[14] analysed peas at times up to 3 hours after shelling, and sprouts up to 2 days after trimming, but failed to detect any change in their ascorbic acid contents. Adam[15] reported negligible losses on holding peas, sliced beans and potatoes for periods up to 4 hours after podding, slicing or peeling.

Blanching accounts for heavier losses than any other canning operation, leaching being the chief cause; only a small proportion of the vitamin C is destroyed by oxidation. The subject has been studied by Adam, Horner and Stanworth[1] and the results have already been referred to earlier in this chapter. The losses are generally of the order of 10 per cent. to 50 per cent. in water blanching and 10 per cent. to 30 per cent. in steam blanching. The period between blanching and filling the vegetables into the cans is generally short, but Adam[15] has shown that a slight fall in vitamin C content may occur if this is prolonged to 3 or 4 hours.

As vitamin C is sensitive to oxidation at high temperatures some loss may be expected during processing of the vegetables in retorts or automatic pressure cookers, but the risk is reduced if the cans are given an efficient heat exhaust and closed with the minimum of headspace. Horner[14] found that a reduction of headspace in A2 cans of peas from 35 ml. to zero resulted in a rise of about 10 per cent. in the vitamin C content, whereas an increase of headspace to 65 ml. caused a drop of 20 per cent. More recently, Adam[15,16] made similar tests on peas, broad beans, stringless beans, carrots, parsnips and sprouts; he found the average retention of vitamin C in cans with 0 ml. to 5 ml., 25 ml. and 45 ml. headspaces to be 68 per cent., 50 per cent. and 40 per cent. respectively. The same worker noted that there was less loss of vitamin C in plain cans than in lacquered cans, and that the loss on processing was reduced by raising the closing temperature of the cans. Adam[15] has also shown that there is little difference in the vitamin C content of vegetables cooked for 35 minutes at 116° C. and for 11 minutes at 127° C.

The total loss of vitamin C during canning has been very fully studied by Kohman,[3,18] Olliver,[17] Fellers,[19,20], Hoff,[5] Adam[15,16] and others. The results obtained by these workers show considerable variation—probably as a result of differences in the technique of blanching, filling and exhausting the cans—but a fairly broad statement of the findings can be given. The loss of vitamin C in such vegetables as peas, stringless and broad beans, diced carrots and beets, sprouts, spinach and asparagus is about 50 per cent. to 70 per cent. when determined in the drained solid material, and 30 per cent. to 55 per cent. if the liquid contents are included. Whole roots (carrots, beetroot, turnips, and parsnips) and whole potatoes lose about 35 per cent. to 55 per cent. when determined on the solids only and 20 per cent. to 50 per cent. if the liquid portion is taken into consideration. The amount of vitamin C available in the drained material is generally very similar to that present in vegetables cooked by domestic methods, but quite half as much again is available if the liquid contents of the can are utilized.

Losses on storage appear to be slight. Olliver[17] has reported that most canned vegetables held for 6 to 9 months lose about 10 per cent. to 20 per cent. of their vitamin C, but that canned peas may show a more rapid fall. Adam,[16] on the other hand, found canned peas, green beans, potatoes, carrots and sprouts to show negligible losses when stored for periods up to one year from the date of canning. Eddy, Kohman and Carlsson[26] have pointed out that little loss occurs when canned peas are re-heated for the table.

MINERAL SALTS

The loss of mineral constituents of vegetables as a result of cooking and canning has been studied by Horner,[22] who examined the effect of blanching, canning, and home-cooking on the calcium, magnesium, potassium, and phosphorus contents of most of the common English vegetables. For the full results the original paper must be consulted, but the general conclusions were that the mineral losses in canned and home-cooked vegetables are of much the same magnitude. When the liquid contents of the can are used the available mineral salts are increased considerably, but only the potassium and sodium salts are evenly distributed throughout the solid and liquid portions. The calcium content is governed by the hardness of the water used, and with most canned vegetables, except spinach, is generally greater than that of the raw material, but other mineral constituents show losses of the order of 30 per cent. to 70 per cent. when calculated on the drained solid contents of the can.

More recent work by Adam, Horner and Stanworth[1] has indicated that losses of mineral substances on blanching (the only stage at which these constituents can escape) amount to about 20 per cent. to 30 per cent. in peas, beans and diced roots, and about 10 per cent. to 20 per cent. in whole roots and potatoes. The corresponding losses, calculated on the drained solids, are 45 per cent. to 55 per cent. for the smaller vegetables and 35 per cent. to 45 per cent. for the larger.

CARBOHYDRATES

Comparatively little work has been done to determine the loss of soluble carbohydrates during canning operations, but Magoon and Culpepper[23] have stated that peas lose about 30 per cent. and spinach 50 per cent. to 70 per cent. of their total sugars during blanching. Horner[24] reported 23 per cent. loss in peas, 8 per cent. in whole stringless beans, and 13 per cent. in whole carrots as a result of blanching for 3 minutes at 100° C. The sugars are subsequestly distributed uniformly through the solid and liquid contents of the can. Adam, Horner and Stanworth[1] found that the losses of sugars on blanching generally amounted to about 20 per cent. to 30 per cent. in peas, beans and diced roots, and about 10 per cent. to 20 per cent. in whole roots and potatoes.

PROTEINS

Information relating to protein losses is scanty. Magoon and Culpepper[23] found that spinach lost about 10 per cent. of its protein and peas 5 per cent. to 10 per cent. as a result of a 2 to 4 minutes' blanch. Horner's[24] figures for a 3 minutes' blanch at 100° C. were, peas 22 per cent., whole stringless beans 0 per cent., whole carrots 18 per cent. The extent of the losses occurring during blanching and by subsequent distribution between the solid and liquid contents of the can has been studied at Campden. Recent figures by Adam, Horner and Stanworth[1] show that blanching losses amount to about 10 per cent. to 25 per cent. in peas, beans and diced roots, and about 5 per cent. to 15 per cent. in whole roots and potatoes.

FEEDING TESTS

In addition to the work done on the separate nutrients of canned vegetables, much attention has also been given to the effect of diets consisting entirely of canned foods (of which vegetables formed a large part) on the breeding, growth, health, and composition of the body of test animals. Full reports on these investigations are contained in papers by Kohman,[18,25,26] and his co-workers, Macheboeuf, Cheftel, and Thuillot,[27] and Godden and Thomson.[28] These workers agree that a diet of canned foods gives results comparable in all respects to those from diets of the corresponding shop-purchased home-cooked foods.

The evidence on human feeding tests is necessarily less complete, but Cheftel[29] has described an interesting experiment in which fifteen members of a French polar expedition lived for 13 months in perfect health on a diet consisting entirely of canned foods.

CONCLUSIONS

In this necessarily short survey of the effect of canning on the nutritive value of canned vegetables, reference to much interesting work has had to be omitted and particular emphasis has been laid on scientific researches conducted on types of vegetables grown and canned extensively in this country. In many instances the results require confirmation and there are obvious gaps to be filled in, but some general conclusions can be drawn. It appears fairly certain that canned vegetables are at least equal in nutritional value to similar vegetables cooked in the home, and in some cases of greater value. Probably only in the vitamin B_1 content is there any risk that the canned product may be inferior to the home-cooked article. In general, the former has the higher vitamin C content. Losses of mineral salts and carbohydrates are much the same from both methods of cooking. The canner has a distinct advantage over the domestic purchaser in obtaining his raw material fresh from the field, and with those vegetables which show rapid deterioration on storage it is likely that the canned product will have a higher nutritive value than the same vegetable cooked in the home.

Finally, a comprehensive series of feeding tests has shown that no essential nutritive factor appears to be missing from canned foods. This fact, taken in conjunction with the obvious merits of canning as a method of preserving food supplies in war-time, appears to justify the inclusion of canned vegetables as a valuable adjunct to the nation's diet.

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Part IV
CEREALS AS FOOD

(*Papers read at a meeting on 29th October*, 1941)

CHAPTER XIII

THE CHEMICAL COMPOSITION OF WHEAT AND WHEAT PRODUCTS

By R. G. Booth, R. H. Carter, C. R. Jones and T. Moran

Introduction

In this chapter we attempt to give a summarized account of the chemistry of the different parts of the wheat grain, their separation during milling, the milling fractions and the chemistry of white flour and National Wheatmeal.

Structure of Wheat Grain

The grain of wheat is a seed, which in structure resembles a nut. It is botanically a *caryopsis* comprising pericarp (like the shell of a nut) and seed proper.

The pericarp has four layers: (1) outer epidermis or epicarp, (2) mesocarp, (3) cross layer, (4) inner epidermis or tube cells. Of these, two (Nos. 1 and 3) are of major significance, but Nos. 2 and 4 are not easily seen microscopically. Layer No. 1 is built up of long longitudinal and No. 3 of long transverse cells. In milling practice, however, the analogy with the nut is misleading, because the wheat *seed* has no significance as an entity.

It comprises: (*a*) the seed coat, (*b*) the germ or embryo, amounting only to about one-fortieth of the weight of the whole grain. As is well known this is situated dorsally at one end of the grain and separated by its scutellar tissue from (*c*) the endosperm, amounting to between 85 per cent. and 90 per cent. of the weight.

For our purpose the seed coat may be regarded as consisting of three layers,* which for convenience may be numbered consecutively with those of the pericarp: (5) testa or episperm, (6) nucellar or hyaline layer, (7) aleurone layer. The testa is the only layer sharing with the pericarp the function of surrounding the whole grain ; the two innermost layers surround the endosperm, but overlap the germ only slightly. The testa is also of interest because it is the colour-bearing layer, the surrounding pericarp being relatively translucent. The nucellar layer in the ripe wheat is not of general importance, except that there is some evidence that it limits the rate of inward water movement in wetted grain. The aleurone layer is of particular interest. It is, in general, a single layer of large, boldly-characterized cells, amounting probably to about 3 per cent. of the weight of the entire grain. It is believed to be rich in mineral constituents and nutritive factors. The point to emphasize is that although the aleurone layer is botanically part of the endosperm, practically all of it remains firmly attached to the other coats during milling, the rest of the endosperm being substantially separated from it to fill the white flour sack. The aleurone layer is therefore the innermost layer of the separated bran. It is possible that one development in the future of flour milling will be a greater separation of the aleurone layer from the bran, and its inclusion in the white flour. Data on the relative amounts by weight of the various constituents of the grain have been summarized in Table I.

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* For an excellent description of these various layers, reference may be made to a monograph by Fairclough, entitled *A Microscopical Examination of Wheat Grain* (Pamphlet No. 14 of the *Technical Education Series*, published by the National Joint Industrial Council for the Flour Milling Industry, 6, The Hermitage, Richmond, Surrey).

In detail the data are to some extent conflicting. Morever, it is known that the proportions of some parts, e.g., the germ, vary from type to type, and even from one grain to another of a given sample. Average figures would appear to be pericarp 4 per cent., testa and hyaline layer 2·5 per cent., aleurone layer 6 per cent. to 7 per cent., germ 2·5 per cent. (scutellum and embryo proper), and endosperm 85 per cent.

Approximate Composition of Individual Parts

Before considering the individual parts of the bran it is convenient to give the composition of the bran as a whole, i.e., as a technical entity, including both the pericarp and the seed coat. This composition is shown, together with that of germ and white flour (representing the endosperm) in Table II, based on samples examined by us.

Owing to the large difference in ash content between endosperm and bran, the ash determination is customarily employed as a measure of the degree to which bran powder is present in flour. In endosperm quite free from bran the figure is probably about 0·25 to 0·3 ; since bran has about 5 per cent. ash, the ash content of ordinary straight-run flour indicates that about 3 per cent. to 5 per cent. of

TABLE I

<table>
<tr><th></th><th>Epicarp</th><th>Mesocarp</th><th>Cross layer and tube cells (Endocarp)</th><th>Testa</th><th>Hyaline layer</th><th>Aleurone layer</th><th>Total bran</th><th>Germ*</th><th>Endosperm</th></tr>
<tr><td>Mège-Mouriès (cited by Jago)[1]</td><td>0·5</td><td>1·0</td><td>1·5</td><td colspan="2">2·0</td><td>—</td><td>—</td><td>2–3</td><td>—</td></tr>
<tr><td>Kent-Jones[2] .. .. ..</td><td>0·5</td><td>1·0</td><td>1·5</td><td>2</td><td>?</td><td>5</td><td>13</td><td>2</td><td>85</td></tr>
<tr><td>W. Kranz[3] .. .. ..</td><td colspan="3">3–4</td><td colspan="2">2–3</td><td>9–10</td><td>—</td><td>2–3</td><td>80–85</td></tr>
<tr><td>Girard et Lindet[4] .. ..</td><td colspan="3">4·5</td><td>1·1</td><td colspan="2">8·8</td><td>13·3–15·7
Mean 14·4</td><td>1·25–1·85
Mean 1·4</td><td>82–85
84</td></tr>
<tr><td>Grischenko[5]</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Range for both 2·6–3·3</td><td></td></tr>
<tr><td>On soft Russian .. ..</td><td colspan="3">5</td><td colspan="2">2·9</td><td>6·5</td><td>—</td><td>2·7</td><td>82·4</td></tr>
<tr><td>On hard Russian .. ..</td><td colspan="5">7·7–8·9</td><td>8·2</td><td>—</td><td>2·9</td><td>80·9</td></tr>
<tr><td>Neumann[6] .. .. ..</td><td colspan="5">5</td><td>7–9</td><td>—</td><td>2–3</td><td>83–85</td></tr>
<tr><td>Percival[7] .. .. ..</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>7·8–8·6</td><td>2·8–3·5</td><td>87–89</td></tr>
<tr><td>Fleurent: mostly European wheats (cited by Maurizio)[8]</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>14·2–16·2</td><td>1·06–1·57</td><td>82·5–84·1</td></tr>
<tr><td>Fleurent: Russian, Algerian, and Canadian wheats (cited by Bailey)[9] .. .. ..</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>13·0–13·5</td><td>1·5–2·05</td><td>85</td></tr>
<tr><td>Scott[10] .. ..</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>85·7–88·3</td></tr>
<tr><td>Kretovitch[11] .. .. ..</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>11·6</td><td>—</td><td>—</td></tr>
<tr><td>Bailey[12] .. .. ..</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>82</td></tr>
<tr><td>Kick[13] .. ..</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>82</td></tr>
<tr><td>Halton and Barton Wright[14] ..</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>—</td><td>86</td></tr>
</table>

* "Germ" in the above table generally represents embryo + scutellum, but the values below 2 per cent. may be mainly embryo. The term "germ" as applied to wheat has not been given a precise definition until very recently.

TABLE II

	White flour (endosperm)		Bran		Germ	
	Range Per cent.	Typical fig. (75 per cent. ext.) Per cent.	Range Per cent.	Typical figure Per cent.	Range Per cent.	Typical figure Per cent.
Moisture content	12–16	13·8	10–15·5	12·5	10–14	13·5
Oil	1–1·5	1·2	3–5·4	4·7	6–11	10·8
Protein (Nx 5·7)	6·2–14·1	12·0	11·8–17·3	15·0	17·2–27·4	25·9
Ash	0·32–0·55	0·55	4·2–7·6	4·65	4·0–5·0	4·1
Fibre	0·2 or less	0·2	7·5–11·0	7·9	1·8–4·3	1·9
Carbohydrates		72·25		55·25		43·8

powdered bran is present. Although the ash content of the endosperm undoubtedly varies from one wheat to another in ordinary mixtures of wheat, such as the British miller must use, the differences large compensate one another, and the ash content is a useful indication of grade of flour, and of degrees of technical efficiency in the milling of comparable grades. Its intensive application to the analysis of flour milling processes is limited by the fact, appreciated fully only in recent years, that the bran is heterogeneous. Although the bran as a whole contains nearly 5 per cent. ash, the aleurone layer alone accounts for the greater part of this, so that the pericarp layers, which are much the more fibrous, have a relatively low ash content. Certain of the streams in a flour mill contributing to the offal show a marked concentration of pericarp relative to the seed coat proper. Their ash content might suggest that they were fairly rich in endosperm, whereas in fact they comprise mostly fibrous outer coatings.

The ash content of flour is also useful as a rough indication of its vitamin B content, though this correlation is less valid at present than it was prior to 1940–41, owing to recent changes in milling technique and discoveries in connection with the distribution of vitamin B_1 in grain, which are considered more fully later. For data on the relative compositions of the individual structural components of the bran, cereal chemists are indebted almost solely to the early work of A. Girard.[4] He reported 4·5 per cent. as the ash content and 2·8 per cent. to 3·1 per cent. as the nitrogen content of whole bran. From microscopical investigations he concluded qualitatively that the pericarp layers are composed of lignin, i.e., cellulose plus small amounts of nitrogeneous substances. The hyaline layer and aleurone cell walls are also composed of cellulose permeated with nitrogeneous matter, the contents of the aleurone cells being rich in protein material and oil. Quantitatively he proceeded on lines which leave little doubt of the soundness of the figures given in Table III, with one exception to be referred to later. In this table the protein factor of 5·7 has been used, so that Girard's original figures have been amended slightly.

Since the whole bran is 14·35 per cent. of the grain, the figures of Table III indicate the following contributions to the percentage protein content of the grain as a whole:

Pericarp Per cent.	Testa Per cent.	Hyaline plus aleurone layers
0·316	0·163	2·00

The substantial contribution of the last-named component will be noted. Girard's figures for non-nitrogenous matter or cellulose were obtained by difference, and the fat by an acid digestion and maceration procedure. The pericarp was analysed after direct separation, but the hyaline plus aleurone layer figures were obtained by differential calculation from those for the whole bran after analysis of the testa, which was isolated through removal of other tissues by reagents to which it alone was resistant. Consequently the ash content given for the testa is conjectural. It is likely that it should be lower and that of the aleurone layer higher than indicated. We have found the opinion widely held that the ash content of the aleurone layer exceeds 8 per cent., whilst that of the pericarp is about 2 per cent. So far as we can trace, this is based solely on the work of W. Kranz,[3] who gives the data shown in Table IV.

TABLE III (After Girard)

Component of bran	Percentage by weight of whole bran	Per cent. of whole grain	Composition of component	
Pericarp	31	4·45	Water	11·55
			Non-nitrogenous lignin ..	79·5
			Protein (N × 5·7) ..	7·1
			Ash	1·85
				100·00
Testa	7·7	1·1	Water	11·9
			Non-nitrogeneous matter	67·3
			Protein	14·8
			Ash	6·0
				100·0
Hyaline layer plus aleurone layer	61·3	8·8	Water	11·8
			Cellulose	50·5
			Protein	22·6
			Fat	9·1
			Ash	6·0
		14·35		100·0

TABLE IV (After Kranz)[3]

Constituent of wheat grain	Per cent. by weight	Ash content (Per cent. of dry substance)
Pericarp	3–4	2·0–2·5
Testa (presumably plus hyaline layer)	2–3	—?
Aleurone layer	9–10	Above 8·0
Endosperm	80–85	0·3–0·4
Germ	2–3	5·0
Entire grain	—	1·8–2·0

Kranz gives no experimental details or information as to the source of his data, which seem to include an unaccountably high value for the proportion by weight of the aleurone layer. The relative ash contents of endosperm, aleurone layer, and pericarp are confirmed by other experience. Here it may be pointed out that Bennion[49] extracted substantial proportions of soluble fractions of very high mineral content from small quantities of aleurone layer obtained by dissection. Simon[15] stated that the outer skin of the grain had 1·85 per cent. ash (which agrees with the figure already quoted from Girard). Bennion also found the nitrogen content of the aleurone cells from Amber Durum wheat to be 2·7 per cent., corresponding, by factor 6·25, to 16·9 per cent. protein or by the more usually adopted factor of 5·7 (see Teller and Teller[16]) to 15·4 per cent. It is well known that bran contains large proportions of matter readily water-soluble. This, from the microscopical appearance of the various coats, is probably derived mainly from the aleurone layer, which appears to be rich in oil globules and in water-soluble granular material. Little is known about these water-soluble substances. Kretovitch[11] confirmed Teller and Teller in disproving the existence of gliadin in the aleurone cells and found the proteins to be chiefly glutenin and albumen. Kretovitch also found no sugar in the aleurone layer, although he found the outer layers of the endosperm to contain five times the amount of sugar present in the inner endosperm. Table V gives the information available in the literature about distribution of sugars.

TABLE V

	Wheat flour	Germ	Bran	
			Coarse	Fine
	Per cent.	Per cent.	Per cent.	Per cent.
Total sugar (C and B)	1·0	9·2	2·4	2·9
Reducing sugar (C and B)	0·1	0·2	0·2	0·2
Glucose and fructose (G)	0·12	—?	0·1	
Sucrose and fructosides (G)	0·5	12·0	5·0	
Sucrose (C and B)	0·2	5·2	2·0	2·4
Raffinose (C and B)	0	4·0	—	—
Laevosin (G)	0·5	—?	1·0	
„ (C and B)	0·6	0	—?	—?

Values marked C and B from Colin and Belval.[51] Values marked G from Geoffroy.[52]

The sugar found in the bran is almost certainly located in the aleurone layer. Girard and Lindet also adduced good reasons for citing the aleurone layer as the origin of the 15 per cent. of non-nitrogeneous water-soluble matter which they found to be present in bran. In our own experience we have found four or five times as much sugar in a low grade flour as in a high grade. This, supporting Kretovitch, is more likely to be ascribed to differential composition of successive zones of endosperm than to the presence of cells of the aleurone layer in quantity. There is little doubt as to the existence of a marked gradient in concentration of various substances from inner to outer endosperm. Thus Cobb, in a classic paper of the last century, found that the gluten content rose progressively from 7·4 per cent. in the interior to 16·5 per cent. in the outermost zone of the endosperm, the rise being steepest nearest the outermost zone. There is some evidence that other factors, important in nutrition, are also relatively abundant in the outermost layer of endosperm.

Composition of Whole Wheat Grain

In common with plant products generally, wheat shows a considerable range in composition according to variety, climate, and cultural conditions. Most important of all—commercially—are the variations in quantity and quality of the endosperm proteins, which largely determine the values of different varieties from the standpoint of the baker or biscuit maker. These aspects are concerned primarily with physical, as distinct from nutritional, properties of doughs ; it is not possible to discuss so wide a subject here. Nor can any account be given of the numerous investigations of enzyme content and activity, notwithstanding their fundamental relation to panary feremenation. Attention must be confined to the range of composition generally encountered in the proximate constituents, and to figures for an average mixture of wheats as milled for breadmaking flour (Table VI).

TABLE VI

	Whole wheat Per cent.	Average mixed grist Per cent.
Moisture	8 –22	12·2
Oil	1·2– 2·5	1·8
Protein (Nx 5·7)	7·5–18·0	13·2
Fibre	1·7– 2·9	2·1
Ash	1·2– 2·1	1·7
Carbohydrates	—	69·0

The effect of cultural conditions upon the yield and composition of the wheat grain has been the subject of world-wide investigation during the greater part of the last century. A mass of data has accumulated in the literature, from which we may quote, as one example only, the effects of manuring upon yield and nitrogen content of English wheat grown continuously since 1852 upon some of the Rothamsted Broadbalk plots (Table VII).

The Mineral Constituents of Wheat Flour and Germ

Figures quoted in the literature are given in Table VIII. Fluorine, molybdenum and vanadium have also been investigated. There is a considerable range of variation due to wheat variety and cultural conditions—in particular, to soil type and available water supply. Thus the mineral composition of wheat grown under dry-farm conditions in Utah in the United States, reported by Greaves *et al.*, is somewhat different from the mean of other available figures. The presence of selenium in wheat has been observed only in samples grown on seleniferous soils, e.g., of Alberta, Canada, and Dakota in the United States.

TABLE VII

	Yield/acre (average 51 years) Bushels grain	Total protein (N per cent. × 5·7) (Season 1928)
Unmanured	13	8·89
Farmyard manure	36	10·83
Minerals	15	9·69
,, + single NH_4 salts	24	9·23
,, + double NH_4 salts	33	9·69
,, + treble NH_4 salts	37	10·49
,, + single nitrate	27	9·06
,, + double nitrate	33	10·26
Double NH_4 salts alone	21	9·63

Many early figures quoted for S and Cl are completely valueless, since they were determined on dry-ashed samples where loss of a part of the original content of the element had undoubtedly taken place.

We are indebted to Dr. N. L. Kent for the mineral survey in Table VIII.

At the present moment attention is more particularly directed to the calcium and iron contents of wheat and its products. Table IX gives figures determined in these laboratories for the two elements in three varieties of wheat, and for the calcium contents of a wheat mixture and of the bran, germ, and flour milled commercially from it.

TABLE IX

(Figures are on a 15 per cent. moisture content basis)

	Total Ca (mg./100 g.)	Total Fe (mg./100 g.)
Manitoba wheat	32·4	4·60
Plate wheat	41·7	5·14
English wheat	43·6	4·01
Mixed wheat	38·4	4·2
Bran	90·4	4·8
Germ	46·7	6·1
White flour	15·9	0·9

In view of the importance now attaching to the phytate content of bread, the figures ascertained for total phosphorus and phytate phosphorus in three varieties of wheat are shown in Table X. The table also shows figures for three commercial wheat mixtures and for purified bran and germ.

TABLE VIII

MINERAL CONSTITUENTS OF WHEAT, FLOUR AND BRAN (mg./100 g. dry basis)

	Wheat		White flour		Bran		Source of information*
	Mean	Range	Mean	Range	Mean	Range	
Ag	0·05	—†	0·04	—	0·1	—	88
Al	0·3	—	1·1	0·1–2·0	2·0	1·3–2·7	57, 74, 121, 124
As	0·01	—	0·001	—	0·01	—	83
B	0·5	0·03–1·6	0·2	0·05–0·4	—	—	56, 63, 89, 94, 98, 119
Br	0·8	0·14–2·5	0·1	0·09–0·12	—	—	68, 85
Ca	51·4	22·0–98·0	20·2	10·2–30·9	118·5	93·5–187·0	40, 64, 67, 75, 77, 78, 79, 91, 95, 100, 109, 111, 114, 115, 118, 120, 121, 128
Cl	76·5	7·6–203·0	69·0	43·0–85·0	71·0	38·7–103·4	64, 68, 91, 95, 110, 114, 118, 119
Co	0·02	0·001–0·06	0·009	—	0·001	—	53, 58, 89, 101
Cu	0·7	0·36–1·67	0·2	0·08–0·28	1·46	1·2–1·64	64, 66, 72, 74, 75, 76, 93, 97, 106, 112, 114, 121, 126
Fe	5·1	1·84–8·55	1·4	0·5–2·8	14·1	5·5–26·7	64, 67, 74, 75, 77, 81, 95, 97, 104, 110, 113, 114, 117, 118, 121, 123
I	0·014	0·0001–0·044	0·0017	0·0003–0·003	0·0016	—	73, 74, 80, 96, 116
K	453·2	276·0–591·0	151·0	110·0–175·0	1265·0	960·0–1460·0	59, 75, 77, 84, 91, 95, 110, 114, 118, 119, 121, 128
Li	0·5	—	0·2	—	—	—	89
Mg	157·0	63·0–239·0	30·0	17·0–43·6	565·0	409·0–723·0	67, 75, 77, 78, 84, 95, 110, 114, 115, 118, 120, 121, 128
Mn	4·0	1·2–8·0	0·8	0·3–2·0	11·9	1·3–31·1	59, 64, 65, 70, 71, 74, 82, 83, 84, 89, 93, 97, 103, 105, 106, 107, 108, 114, 117, 121
Na	24·0	1·5–70·0	19·3	3·0–51·7	30·2	23·7–45·5	59, 77, 95, 110, 114, 118, 119
Ni	0·14	0·04–0·24	0·15	—	0·04	—	58, 59
P	380·0	190·0–567·0	126·5	76·0–183·0	1305·0	675·0–1650·0	39, 40, 54, 60, 64, 67, 75, 77, 78, 79, 84, 90, 91, 95, 100, 110, 114, 115, 118, 120, 121, 122, 128
Pb	0·08	0·00–0·95	0·1	0·00–0·11	0·3	0·0–0·35	86, 88, 112
S	196·0	91·0–450·0	132·0	47·0–210·0	165·0	123·0–255·0	60, 75, 87, 96, 99, 110, 114, 120, 128
Se	1·2	0·00–6·3	1·7	0·00–6·3	—	0·0–8·8	69, 92, 102, 109, 125, 127
Si	12·1	4·7–48·5	2·8	0·65–5·0	20·5	13·5–24·0	77, 110, 118, 119, 121
Sn	0·11	—	0·14	—	0·19	—	88, 89
Ti	0·085	0·08–0·09	0·03	—	0·46	—	61
Zn	4·4	1·4–10·0	1·9	0·7–4·5	17·7	3·8–56·2	55, 62, 97, 101, 107, 112, 121

* The numbers refer to the list of references. † A dash in the table indicates the absence of relevant data.

Figures for commercial bran and germ vary according to the relative purity of the products, but roughly it may be said that phytate P constitutes 70 per cent. to 75 per cent. of the total P in the whole wheat, 85 per cent. to 95 per cent. of the total in bran, 40 per cent. to 50 per cent. of that in germ, and 30 per cent. to 40 per cent. of that in white flour (75 per cent. extraction). Similar figures for straight-milled flours of various extractions are given in Table XI (on 15 per cent. moisture basis).

TABLE X

	Total P mg./100 g.	Phytate P mg./100 g.	Phytate P as per cent. total P
Manitoba wheat	324·5	233·1	71·85
Plate wheat	408·7	308·9	75·58
English wheat	382·8	278·6	72·76
Wheat mixture No. I	343·2	245·6	71·57
,, ,, No. II	330·9	233·5	70·57
,, ,, No. III	315·2	226·7	72·07
Bran, purified	1358·0	1200·0	88·4
Germ, ,, ...	1201·0	573·1	47·69

TABLE XI

Straight run flour	Total Ca mg./ 100 g.	Total Fe mg./ 100 g.	Total P mg./ 100 g.	Phytate P mg./ 100 g.	Phytate P as per cent. total P
70 per cent.	18·7	1·0	103	31·9	31
75 ,,	19·0	1·0	114	41·2	36·2
80 ,,	22·0	1·7	155	77·3	49·8
85 ,,	25·7	2·5	197	113·3	57·6

For commercial 85 per cent. wheat meals, our figures average 220 mg./100 g. for total P, and 125 mg./100 g. for phytate P, the latter constituting approximately 57 per cent. of the total. The phytic acid figures were determined by W. J. S. Pringle and have been published in detail in a separate paper[39] together with details concerning the fate of phytic acid during baking.

Geoffroy[17] gives the following distribution of phosphorus in organic combination in flour (73 per cent. extraction):

	mg./100 g. flour
P in combination with starch	43·6
P as phytate	40·2
P as lipoid	16·2
P as nucleoproteins	14·0
Total organic P	114·0

This comprises practically the whole of the P present in the flour. Geoffroy obtained a figure of 118 mg. total P per 100 g. flour as determined on the ash.

NUTRITIONAL ASPECTS

(i) *Minerals.*—It is clear that wheat is not rich in any of the mineral elements known or suspected to be of importance in human nutrition. White flour is more deficient in these elements than wholemeal flour or flour of intermediate extraction. The iron content of wheat, because of the quantities of flour consumed in one form or another, makes an appreciable contribution to the daily requirements, and this is especially true of higher extraction flours. Most authorities regard the iron of cereals as having a high availability, but this view is not universally accepted, and there is in any event some doubt as to the actual proportion of the total iron that is utilized by the body. The availability of cereal calcium, it must be remembered, depends to a considerable extent upon the amount of phytic acid present in the cereal and in the rest of the diet, and probably also on the amount of magnesium. In some instances the excess of phytic acid may make a cereal product, such as wholemeal flour, a calcium liability instead of an asset.

It was with this possibility in mind that in May, 1942 (only 2 months after 85 per cent. extraction had become compulsory) a start was made in fortifying National flour with calcium carbonate at the rate of 7 oz. per sack of 280 lb. The addition of 2 lb. of skim milk powder begun in March, 1943, also makes bread a better source of calcium.[50]

(ii) *Carbohydrate.*—Little need be said about this as it consists almost exclusively of starch and cellulose. Only in grain which has been damaged before milling, and has become moist enough for germination to take place, is there any appreciable amount of sugar.

(iii) *Protein.*—Chemical figures for the protein content of wheat, flours and offals do not give a complete picture of their relative values in nutrition. Boas Fixsen *et al.*[18,19], Chick and Work[20] and many others have demonstrated the fact that the biological value of whole wheat proteins is higher both in protein-sparing and in growth-promoting effect than that of low extraction flours. In other words, the longer the extraction, the higher the biological value of the protein.* Relatively little is known, so far as humans are concerned, about the biological value of the protein of wheat offals, so that it cannot be said whether this phenomenon is due to a supplementing effect between endosperm proteins and those of the integuments and germ, or to a considerably higher intrinsic biological value in the latter, but some available evidence suggests that the supplementing hypothesis is more likely to be true.

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*See also Chapter XIV, pp. 187 and 188.

The addition of skim milk powder, mentioned above, containing approximately 35 per cent. of first-class animal protein, must necessarily raise the biological value of bread protein a little, though by reason of the small percentage added, no such improvement could be satisfactorily demonstrated by experiment.[40]

(iv) *Fat.*—The quantity of fat and its location in wheat have been shown in Tables II and III. The nature of this fat is of chemical and nutritional importance, even though it is present in the whole grain in relatively small amounts. Unsaponifiable matter is present to the extent of approximately 5 per cent. in fat from all fractions of the wheat grain except the bran; bran fat contains approximately 12 per cent. This unsaponifiable matter, which consists principally of sterols and higher alcohols, is of importance in connection with vitamin E. The true fat is rather remarkable in containing a high percentage of unsaturated acids—the ratio of saturated to unsaturated according to Barton-Wright[21] is 16 per cent. to 84 per cent., and Sullivan and Bailey,[22] and Hilditch[23] agree in placing the amount of the nutritionally important unsaturated fatty acids, linoleic and linolenic, high in wheat fat. It is not yet known whether these acids are essential in human nutrition, but their importance in both growth and reproduction in rats has been stressed by Smedley-Maclean,[48] Burr and Burr,[24] and others.

(v) *Vitamins.*—The vitamin content of wheat and wheat products has recently received considerable attention. This has been largely confined to the B group of vitamins, but, before giving details of the average content of some B factors, reference should be made to the fact that wheat is entirely lacking in vitamin D, and contains no appreciable amount of vitamin A. Until recently the carotenoid pigment, fairly even distributed throughout the wheat grain and largely destroyed in flour bleaching, was thought to be a vitamin A precursor. Zechmeister and Cholnoky[25] have summarized the most up-to-date information on the matter and have added the evidence of chromatographic analysis, all of which points to the fact that this pigment is for the most part xanthophyll, and that the vitamin A value of wheat is, therefore, negligible or nothing.

The claim has recently been made[41] that wheat contains a considerable quantity of vitamin C—it has been known for a long time that germinated wheat is rich in C—but this is of little importance for human nutrition as it is almost entirely destroyed when bread is baked.

Table XII shows approximate average values for flour-milling raw materials and products. The vitamin B_1 and riboflavin values are based almost exclusively on estimations carried out by one of the authors, while the figures in other columns are derived from the literature.[26,27,28,29,30,31,33,42,43]

TABLE XII

Material	Aneurine (B_1) I.U./g.	Riboflavin µg/g.	Nicotinic acid µg/g.	Pyridoxine µg/g.
Mixed grist	1·35	2·5	58	4–7·6
Patent flour	very low	0·5	—	—
68–70 per cent. exn. straight-milled flour	0·25–0·3	—	—	—
72 per cent. exn. straight-milled flour	0·35	0·8	11	2·0
75 per cent. exn. straight-milled flour	0·4–0·5	1·0	—	—
85 per cent. National flour ..	1–1·1	1·7–2·1	20	3·5
Weatings	4–5	6·3	—	10–11
Bran	2–2·5	6·9	50	—
Germ (commercial)	8·0	11	35	10–16

A big advance was made in our knowledge of the distribution of vitamin B_1 in the wheat berry when Hinton[46] discovered the very high value of *ca.* 40 I.U./g. for the scutellum component of germ and a relatively very low value of *ca.* 40 I.U./g. for the embryo portion, a finding that has since been confirmed by Ward.[47] This fact explains the observed differences in the distribution of B_1 in mill fractions when "dry" or conditioned wheat is milled; in the former case the scutellum is friable and tends to be broken up and find its way into floury fractions, whereas conditioned wheat has a tough leathery scutellum which tends to pass into the branny "offals."

It cannot yet be said that average values for the components of the B_2 complex have been established with any certainty, as there are still considerable difficulties to be overcome in the techniques of assay, particularly in respect of nicotinic acid. Furthermore, variations in B_1 content from the above figures + 30 per cent. or − 20 per cent. should not be considered at all abnormal. As an example, it has been shown by one of the authors,[32] and confirmed and extended by Slater and Rial,[34] that the corresponding average B_1 values for Australian wheat and some of its products are appreciably higher than those given in the above table.

The distribution of vitamin E in wheat has been studied by Binnington and Andrews,[44] Moore and Tosic[45] and by one of the present authors (unpublished data), and agreement has been reached in the conclusion that this vitamin is by no means solely confined to the germ but is present also in the endosperm. Even 70 per cent. extraction flour has been found by Moore and Tosic and the writer to contain a considerable proportion of the total vitamin E of the grain. The E content of the whole wheat is of the order of 3 to 5 mg./100 g.

(vi) *Enzymes.*—Wheat is known to contain a considerable number of enzymes, the majority of which are found to increase on germination. Among those which have been noted are α- and β-amylase, lipase, phosphatase, amylo-phosphatase, phytase and proteolytic enzymes.

The Separations Effected by Milling: National Wheatmeal

In making ordinary types of baked goods, the grain must be ground so that the well-known processes of admixing ingredients, preparation (which in breadmaking is fermentation), and cooking can be followed. In general, when wheat is ground the outer parts of the grain are less easy to pulverize than the endosperm. It was discovered early in history that through bolting, or the use of sieves, flours or meals of various degrees of refinement may be obtained; the darker, more fibrous, branny coats may be separated as coarser particles from the finer white endosperm. The pre-war extraction of white flour was approximately 70 per cent. This extraction was a technical compromise, the flour consisting of the maximum amount of endosperm and the minimum amount of bran and germ.

The remaining 30 per cent. of the wheat, marketed separately from the flour, was also a compromise. It included between 15 per cent. and 20 per cent. of bran of varying particle size, and in a state nearly free from endosperm, and between 10 per cent. and 15 per cent. of a mixture formerly marketed, in blend with more or less of the less coarse bran particles, under various names, such as sharps or middlings. For some years the commodity was given the term "weatings," provided that it carried a satisfactorily low declaration of fibre content. The mixture referred to results from the confluence of many different "mill streams." These, individually, are mixtures in different proportions of bran particles, cell wall tissue, germ, and endosperm in a mechanically inseparable condition. It is better to say that these separate constituents are not *cleanly* separable. The proportion of endosperm present is high. By extrapolation of the essential ordinary milling processes of rolling and sifting, some of this may be drawn upon, albeit in a progressively impurer form, to increase the length of straight run flour over and above 70 per cent.

Thus early in the war the extraction was increased to 75 per cent., a figure which represented the limit of easy milling separation by peace-time procedure. The flour was still white, but above this point each 1 per cent. meant a gradual but progressively greater deterioration in colour and incorporation of powdered bran.

Table XIII shows certain analytical data for a series of different extraction flours *straight milled* from the same grist. The samples were milled in these laboratories.

TABLE XIII

Material		Ash Per cent.	Protein Per cent.	B_1 I.U./g.	Fibre Per cent.
70 per cent. flour	..	0·445	11·33	0·25	—
75 „ „	..	0·517	11·60	0·42	—
80 „ „	..	0·689	11·90	0·77	0·3–0·4
85 „ „	..	0·892	12·06	0·85	0·6
100 „ (wheat)	..	1·64	12·72	1·3	2·0

Later preparations of 85 per cent. flour, with improved technique (along the lines described towards the end of this paper), have shown appreciably lower fibre than that recorded in Table XIII. The figures generally in Table XIII may, however, be taken as closely portraying the trend now under discussion.

One interesting conclusion from Table XIII is the fact that the protein and B_1 are increased considerably by lengthening the extraction up to 80 per cent. or 85 per cent., whilst the fibre is not greatly increased. At 85 per cent., however, the fibre figure is on a steeply ascending part of the curve, whilst the B_1 figure has further increased, though not so considerably.

When it first became desirable to provide an 85 per cent. flour or meal on a large scale there were serious technical difficulties in raising straight milling extraction to such a high level. That is to say in providing a *flour*, the term "flour" strictly connoting the systematic—and maximum—separation of bran from endosperm throughout the process of manufacture, whereas the term "meal" implies essentially merely a measure of pulverisation. At first, and for some time, the demand was met by the preparation of a "synthetic" or reconstituted long extraction meal as distinct from the straight milled long extraction flour just referred to. There was no technical difficulty here. Most wheatmeals on the market before the war were made by running back into the white flour certain of the offal streams which had been separated in the ordinary course of milling; in the majority of instances the resulting mixture represented about 85 per cent. to 90 per cent. of the wheat.

For convenience in what follows, a wheatmeal may be described as either (i) an irrationally compounded meal or (ii) a rationally reconstituted meal. Most commercial wheatmeals (not, of course, wholemeals) on the market before and during the early part of the war undoubtedly belonged to group (i). They were made by mixing (say) 72 parts of white flour with something of the order of 13 parts of an offal supplement. These figures are approximate only. The point is that in the compounding of the meal, amounts of various offal stocks were used in great excess of the proportions naturally present in the wheat. An additional complication was that the white flour used was not always the straight run, but a low grade. This may give good results technically and nutritionally (particularly high in B_1) but, of course, only at the "expense" of some of the white flour also sold. These meals were not haphazard mixtures but represented locally standardized products which the baker and the miller found were popular in particular districts. Thus certain districts preferred a wheatmeal which showed obvious bran particles.

Including the white flour, the products of the peace-time roller milling of wheat fell into six broad groups as shown for a typical case in Table XIV (which is based on the assumption that 73 per cent. white flour is milled). It should be noted that small amounts of mill materials other than the groups (*c*) to (*e*) also entered into weatings. These, which comprised matter lifted by aspiration during purification ("Purifier Tins"), etc., and *in toto* amounted to about 1 per cent., were largely fibrous in composition.

It should further be noted that the figures of Table XIV must be regarded as typical only. Considerable variation in both quantity and composition of various stocks may be encountered in individual mills.

The next Table, XV, is in two sections. The first section gives results obtained on various commercial wheatmeals from different parts of the country examined prior to the introduction of National Wheatmeal. The symbols used in the second column refer to the groups of roller milling products given in the preceding table. The wide range of fibre and of B_1 content in these wheatmeals will be noted. The effect of using low grade flour, as a basis for the offal supplement, in raising the B_1 content of the resulting meal, is markedly shown in sample No. 2.

Sample X shows a synthetic meal of attractive analysis which, however, could only be produced in small amounts because it is "irrational."

The second section of Table XV shows various "rational" 85 per cent. meals, which could be prepared on a comprehensive scale, including National Wheatmeal. The specification for 85 per cent. National Wheatmeal aimed at (i) the maximum amount of germ, (ii) the maximum amount of B_1, (iii) the minimum of fibre, (iv) a

TABLE XIV

Stock	Approx. quantity (Per cent. of wheat)	Qualitative character	Fibre Per cent.	Ash Per cent.	Protein Per cent.	B_1 I.U. g.
Wheat	100		1·8	1·6	12·3	1·6
(*a*) Flour	73	—	0·2	0·45	11·5	0·3
(*b*) Bran	12–13	Fair-sized pieces of skin, including both pericarp and inner layers. Some endosperm attached	8·0	6·5	14·5	2·0
Weatings composed of:						
(*c*) Fine bran (Pollards)	5–6	As bran, but simply smaller in particle size, little or no germ	7·0	4·0	15·0	3·5
(*d*) Purifier tails (variable in amt.)	2	Much bran. Some endosperm. Some germ ..	6·1	3·2	13·0	2·5
(*e*) Reduction roll tails and "Mill finish"	5	Little bran except as very fine fragment. Much germ. Much cellular tissue. Much endosperm	3·6	3·2	17·0	8·5
(*f*) Germ where separated for sale (amount variable)	0·5					
	100					

TABLE XV

COMMERCIAL WHEATMEALS

Ref. No.	Description and make up	Fibre Per cent.	Ash Per cent.	Protein Per cent.	B_1 I.U./g.
3	13 parts *c* mixed with 72 parts of 72 per cent. *straight run flour*	1·25	0·94	11·4	0·69
2	About same proportion of *c* and some *e* mixed with a *low grade flour* as basis ..	1·5	1·27	12·0	1·605
5	"Coarse brown flour." About 12 parts of *b* mixed with 72 parts of 72 per cent. *straight run flour*	1·6	1·30	11·2	0·88
6	"Fine brown flour" from same firm as 5. Finer branny supplement than in other cases mixed with a *fairly low grade flour*	1·75	1·28	11·8	1·08
4	Rather like 3 but supplement mixed with a grade of flour *below that of straight run* ..	1·2	1·06	12·2	0·98
X	13 parts *e* with 72 parts s.r. flour	0·7	0·87	12·3	1·57
1	A very low grade Plate flour without any offal supplement	0·8	2·46	9·2	1·42
W	National wheatmeal .. .. 73a + 5e + 2d + 5c + 0·5 f.	0·94	0·89	12·2	1·02
Y	A branny rational meal .. .. 73a + 6c + 2d + 4b	1·2	1·05	11·9	0·66
Z	Wholemeal plus white flour in proportions 100/91 ; mixture nominally 85 per cent.	1·05	1·01	11·8	0·8

meal giving a loaf with a crumb or texture as near as possible to white bread. Hence the definition: "A meal containing 85 per cent. of the weight of the clean wheat grain in which is included all the white flour, all the reduction roll tails, mill finish and purifier tails and sufficient fine bran to bring the amount of the mixture to 85 per cent. of the weight of the clean wheat. This flour might also be defined as containing 85 per cent. of the weight of the clean wheat and excluding 15 per cent. consisting of the bran and the pollards." This definition is shown in the form of symbols in the above table. A wheatmeal made in this way should have a fibre content not greater than about 0·9 per cent. and a vitamin B_1 not less than 1·0 International Unit per g. The superiority of the National Wheatmeal over other possible *rational* meals in respect of fibre and B_1 contents will be clear. Thus, sample Y is rational and has a predominantly branny supplement. The close correspondence of the figures given (which are calculated from the basic factors in the preceding table) with those of sample No. 3 (which were determined on an actual commercial meal of this type) will be noted. Sample Z is a possible rational meal of a distinct type. It was considered because its preparation is simple practically, but it was rejected because of its high fibre and low B_1 contents.

On 23rd March, 1942, the Government fixed the extraction to be obtained from *all* home-milled wheat at 85 per cent. and National flour became at once National Wheatmeal. There were "teething troubles," some few mills tending to produce rather branny meals of the type Y. However, close control by means of laboratory examination was exercised from the start and the production of a flour with minimum fibre content and maximum B_1 developed rapidly. Colour was the guiding feature, but paleness implied minimum fibre. The general development consisted in obtaining heavier work from the leading (coarsely fluted) break rolls (this being assisted by the recognition of the suitability of milling the wheat at a much lower moisture content than in peace-time), so allowing the later (finely fluted) rolls to be used more intensively in "cleaning up" the bran. More extended use was also made of finely fluted rolls in the reduction system, leading to a greater separation of endosperm from bran in, for example, fractions (*c*) and (*d*) of Table XIV. In this way the National 85 per cent. flour gradually took the character of a true "*flour*" in the sense already described, rather than of a wheatmeal. The trend is shown in the studies of National flour and bread[35,36,37] which begun in late 1941 and early 1942, a few months before National flour became compulsory.

Of the first series of samples (received up to and including 22nd March, 1942) over 300 in number, approximately 80 per cent. reached the nutritional specification demanding a content of not $<$ 1 I.U. of vitamin B_1 per g. and not $>$ 0·9 per cent. of fibre, laid down by the Medical Research Council in its second memorandum on bread.[38] It is noteworthy that in only about 10 per cent. of these samples was the fibre content $>$ 0·6 per cent., whereas, for the period 23rd March to October, 1942, the percentage of samples reaching this standard was 29·8. A further very marked improvement was observed in the next 6 months period where the comparable percentage was 61·5. In fact, the "national average" fibre content for this period (ending May, 1943) was 0·55 per cent. Concurrent with the falling fibre content there was a slight fall in B_1 (of the order of between 0·05 and 0·1 I.U./g.) but this could not be attributed to changed milling technique as it was largely a result of changed grists.

The problem of obtaining a low-fibre, high B_1, 85 per cent. extraction flour was not made any simpler by the introduction in February, 1943, of groats and barley to the grist, but such diluents have been used without causing any significant changes in the amounts of these constituents. Rye has also been used in grists without causing any serious difficulties in milling technique.

It should be noted that National (85 per cent.) flour contains practically all the scutellum fraction of the germ, and it is this fact which in some respects defines the nutritional value of the flour. One likely future development in flour milling will be the production of a low extraction white flour still containing the scutellum.

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CHAPTER XIV

THE NUTRITIVE VALUE OF BREAD

By D. W. Kent-Jones and A. L. Bacharach

Introduction

The vast majority of bread in this country is made by the yeast fermentation of a dough formed by flour, salt, and water, sometimes with other ingredients, such as small proportions of sugar or fat. In pre-war days, nearly 95 per cent. of the bread was white bread of various types and the average extraction of flour from grain was about 72 per cent., although "divides" existed which enabled patent grade flours to be made and, in consequence, flours rather lower in grade than true "straight run." In the milling of wheat most of the flour is not made directly, but passes through the stage of semolina. The break rolls release various-sized semolinas, some comparatively clean, and free or easily freed from bran "contamination." Other semolinas from the lower break rolls, although submitted to the action of purifiers, are not so clean. When these various semolinas are reduced to flour, there are many flour streams of varying degrees of "purity." Straight-run flour consists of all these flour streams mixed together, but it is possible to make "divides" by segregating various flour streams. In this way patent flour (of a high degree of purity and freedom from bran particles) and low grade flour (of poorer colour and more bran contamination) are produced. Thus, besides the normal straight run white flour, it is possible to have top patent flour of low ash and only minute bran contamination and lower grade flour of high ash and appreciably higher bran contamination.

Since the war, there have been a number of changes in the flour available to the baking industry and the public. It may be of use here briefly to summarize these changes, so that they are on record together, for we do not believe that such a record has been published elsewhere. The price of white (70 per cent.) flour was regulated by Order in September, 1939. In October, 1939, the extraction of all white flour was compulsorily raised to 73 per cent., and a further Order controlling its price was issued in March, 1940. In February, 1941, flour of 85 per cent. extraction was introduced and its use was encouraged by various means; it was called "National

Wheatmeal," and came later to be designated simply National flour. In April of the same year, 75 per cent. was fixed by order as the minimum rate of extraction, and in September, 1941, the availability of National Wheatmeal, if ordered, was made compulsory.

The greatest change in flour and bread policy took place in March, 1942, when 75 per cent. flour was no longer allowed to be used, so that National flour came to represent the lowest extraction flour available. In effect, except for a relatively small quantity of wholemeal and speciality flours, it became the only flour available to the general public, either as such or as bread. After December, 1942, a limited number of specified diluents came into use, the maximum quantities permissible in flour and bread being controlled by the Ministry of Food. In a somewhat different category came separated milk powder, which was added to most flour by January, 1943, and calcium carbonate (*Creta Praeparata*, B.P.), the incorporation of which began in some localities in June, 1942, and was compulsory by August, 1943. National flour is milled so as to contain as much as possible of the germ and the aleurone layer. It thus has most of the nutritional advantages of wholemeal, but is more easily digested and makes a more attractive loaf. When National Wheatmeal was first made compulsory, the product was rather coarse and had a fibre content of 0·8 per cent. to 1 per cent. Subsequently, improved methods of milling were introduced, and these certainly justify the same National flour, as the product is now more a flour than a meal and the fibre content is, in general, near 0·4 per cent. to 0·5 per cent. Later in this chapter some reference will be made to the relative merits of white and brown bread, but it is necessary that the value of bread generally as a foodstuff should first be emphasized. Bread was in pre-war days one of the cheapest foods available; this is even truer at the present time, for not only is flour subsidized so that it is sold below its economic price, but the bread made from it is also subsidized. The following tables gives the number of calories and proteins that can be obtained with one shilling from various foodstuffs.

Although primarily a source of carbohydrate, bread contains useful amounts of protein and other nutrients. The composition of flour and of bread made therefrom is naturally dependent upon the wheats employed, and there is considerable variation between different types of wheat in, for example, protein content. Hence it is difficult to suggest typical analytical data for bread; we have adopted the procedure of quoting those given by McCance and Widdowson in their latest tables.[1]

In addition to normal wheatmeals and wholemeals produced by most millers, many well-known speciality flours have been marketed. The average analytical data for some of these are given in Table III; for the sake of comparison, the figures for white flour and wholemeal (McCance and Widdowson[1]) are again included. It may be emphasized that these figures, being for flour, are not necessarily proportional to those for the corresponding breads; availability of calories, proteins or calcium, for example, may change, absolutely and relatively during baking.

TABLE I

THE COST OF CALORIES AND PROTEIN (OCTOBER, 1941)

Food	Price	Obtainable for 1s. Calories	Obtainable for 1s. Protein = N × 6·25 (g.)
Bread (white)	2d. per lb.	7070	215
Potatoes	4½d. per 3½ lb.	3975	106
Cabbage	2½d. per lb.	215	22
Cheese	1s. 1d. per lb.	1775	105
Butter	1s. 7d. per lb.	2300	1
Margarine	9d. per lb.	4765	1
	5d. per lb.	8655	2
Apples	1s. per lb.	225	1
Eggs	2s. 6d. per doz.	440	32
Milk	9d. per quart	1045	51
Meat (beef)	1s. 3d. per lb.	900	90
Herrings	7d. per lb.	1950	140
Lemon sole	1s. 6d. per lb.	300	42

The figures for calories and protein are based upon those given by McCance and Widdowson.[1]

GENERAL VALUE OF BREAD

It is perhaps not appreciated that baker's bread (as distinct from other flour products, such as home-made bread, biscuits, cakes, etc.) provides the nation with over 20 per cent. of its total calories and over 20 per cent. of its protein. When the other flour products are taken into account, it is found that wheat provides over 35 per cent. of the total calories of the diet and about 35 per cent. of the proteins. Hence the importance of flour and bread in the diet is very clear. Confirmation of these figures is found in the facts disclosed by the British Medical Association in 1933.[2] The B.M.A. then put forward certain diets claimed to be satisfactory for nutrition and available at minimum expenditure. Examination of these diets leads to similar interesting conclusions. Taking as an example that recommended for a man, wife, and one child, aged 1 to 2 years (man value 2·13), in which the weekly quantity of protein came to 1616·2 g. and the calories to 50,575, it is found that the flour and bread supplied about 43 per cent. of the calories and 37 per cent. of the protein.

TABLE II

THE CHEMICAL COMPOSITION OF BREAD AND TOAST

Kind of bread	Water	Sugar	Starch, etc., as glucose	Protein (N × 6·25)	Fat	Calories per 100 g.	Potassium	Calcium	Magnesium	Iron	Copper	Phosphorus	Sulphur
	g. per 100 g.						mg. per 100 g.						
White	32	tr.	54	7·9	0·7	260	115	23	22	1·0	0·07	73	55
White, toasted	19	tr.	64	9·4	0·8	308	137	28	26	1·2	0·08	87	65
Wholemeal ..	37	tr.	44	8·4	1·6	229	238	30	80	2·7	0·16	213	76
Malt	24	19	31	9·1	3·3	271	381	53	78	3·2	0·06	253	115
Currant ..	38	13	33	7·0	3·4	248	250	38	25	2·4	0·09	121	59
"Hovis" ..	39	tr.	41	11·4	3·7	248	243	28	79	3·0	0·09	257	77
"Hovis," toasted	27	tr.	48	13·6	4·4	296	289	33	94	3·5	0·11	306	92

Figures adapted from those of McCance and Widdowson.[1]
Figures for sodium and chlorine omitted; varying quantities of sodium chloride are used in bread-making.

TABLE III

ANALYTICAL DATA OF SOME WELL-KNOWN PROPRIETARY FLOURS

Sample	Moisture	Ash	Protein	Fat	Fibre	Carbohydrates by difference	Calcium	Phosphorus	Vitamin B_1 I.U. per g.	Iron
Hovis	12·2	2·3	15·5	3·2	0·9	65·9	0·05	0·37	1·90	0·003
Daren	13·1	3·1	15·8	2·6	1·0	64·4	0·04	0·38	1·65	0·003
Turog	12·6	1·0	14·0	2·3	0·6	69·5	0·02	0·22	0·85	0·003
Youma	13·2	2·0	11·4	1·1	0·5	71·8	0·02	0·22	1·10	n.d.
Cerovim ..	14·2	1·4	12·6	1·5	1·6	68·7	0·04	0·36	1·60	n.d.

Figures represent parts per cent., except those for vitamin B_1. n.d. = not determined.

We propose now to examine the value of bread in the diet as a source of:

(*a*) Carbohydrates.
(*b*) Proteins.
(*c*) Minerals.
(*d*) Vitamins.

The quantity of fat is normally too small to be of much account.

Bread as a source of carbohydrates.—The main source of carbohydrates in the diet is bread and, as stated, this food together with other flour products provides over 35 per cent. of the total calories of the diet. The next most important sources of calories are potatoes (less than one-third of the calories provided by the wheaten products), then sugar (at the present ration less than half the calories provided by potatoes) and finally the fats. Not only does bread provide a large proportion of the carbohydrate in the diet but it provides it in a particularly cheap and palatable form.

According to McCance and Widdowson,[1] white bread has a higher calorific value than wholemeal bread. They give 260 calories per 100 g. for white bread and 229 calories per 100 g. for wholemeal—a reduction of 12 per cent. on white bread. With respect to digestibility the usually accepted figures are 92 per cent. and 87 per cent. for white flour and wholemeal flour respectively. The latest work of Macrae, Bacon, Hutchinson and McDougall[3] gives 96·1 per cent. for white bread and 86·9 per cent. and 87·1 per cent. for different types of wholemeal.

Bread as a source of proteins.—Although it is generally known that bread is particularly useful as a source of carbohydrates, its importance as a source of protein is not always appreciated. Admittedly, this protein is only graded as second-class, but the difference between first and second-class protein is now not thought to be quite as marked as it was at one time. Bread contains about 8·0 per cent. to 8·5 per cent. of protein and most of that (about 80 per cent.) is glutelin, glutenin and the prolamin, gliadin. It has to be remembered that there is not the same difference between the protein contents of white and wholemeal bread as there is between the protein contents of the respective flours, owing to the fact that brown types of flour take on average 1½ gallons to 2 gallons of extra water a sack (280 lb.) in dough making. It is generally agreed that the nutritive value of the proteins of the whole grain is distinctly higher than the proteins of white flour. It is also necessary to bear in mind the difference in the digestibility of protein of white and brown bread. Numerous figures have been given and, at any rate until recently, the generally accepted figures were 89 per cent. for the protein of white flour and 81 per cent. for the protein of brown flour. The latest figures given by Macrae, Bacon, Hutchinson and McDougall[3] for bread are 91 per cent. for white bread, 85·3 per cent. for fine wholemeal bread and 85·7 per cent. for coarser wholemeal bread.

Breese Jones[4] confirmed the findings of Osborne and Mendel[5] as to the nutritive value of wheat proteins, namely, that wheat proteins considered in their entirety are adequate for promoting normal growth if eaten in sufficient amount. The proteins of the wheat kernel are not greatly inferior to casein, to edestin, or even to the total protein of milk. Also, it has to be remembered that bread is eaten in conjunction with other foods such as cheese, meat, and milk, and the proteins of these supplement those of bread in more than a simple additive way and make good any defects of the latter.

Bread as a source of minerals.—When the question of minerals is considered, the difference between white bread and wholemeal have especially to be borne in mind. The top patent flour of pre-war days had an ash content of only about 0·36 per cent. and true straight-run flour of 72 per cent. extraction about 0·45 per cent. The average ash content of 75 per cent. extraction flour is about 0·51 per cent. so that such flour contains a rather higher proportion of the outer portions of the grain than does patent flour. National (85 per cent.) flour has on average an ash of 0·80 per cent. and wholemeal an ash of 1·5 per cent. Naturally the majority of this ash is potassium phosphate, but the differences in some of the minor but important constituents are interesting. According to McCance and Widdowson,[1] white flour has 0·92 mg. per 100 g. of iron and 0·07 mg. of copper against 2·92 mg. of iron and 0·38 mg. for copper in wholemeal. The figures for National flour are intermediate but are generally closer to the wholemeal figures than to those for white flour. It should be emphasized that the iron of wheat, and especially of white flour, is present in a highly utilizable form. McCance and Widdowson give the following figures of "available" (ionizable) iron, as percentages of the total iron present:

White bread	89 per cent.
Wholemeal bread	79 ,,
White flour	93 ,,

On this basis half a pound of white bread supplies about 2 mg. and half a pound of wholemeal bread nearly 5 mg. of available iron. There is some evidence to show that the phytic acid of bran, and that part thereof present in wholemeal or National flour, can render unavailable or less easily assimilable the iron of flour and bread.[12] This conclusion has been challenged, not on the experimental evidence presented, but because many peoples are known to exist largely on whole-grain cereal diets without developing any signs of nutritional anæmia, to which adult women would be specially prone, as their daily requirements (over 15 mg.) are held to be more than three times those of adult men. This view is current in Great Britain, but United States authorities put the "recommended allowances" at 12 mg. per day for both men and women with an increase of 3 mg. daily for pregnancy and lactation.[13] According to Sherman,[14] our views of iron "availability" are now once more in the melting-pot, and he takes the *total* iron of any food as a reasonably accurate indication of the available iron.

If it is essential for the bread portion of a diet to provide this element, it may be asked whether it is necessary for it to come from long extraction flour? Just as fortification of white flour with vitamin B_1 and maybe with calcium has been an accepted policy, so iron could be added, if nutritional authorities thought this desirable. Although the Medical Research Council has, through the Accessory Food Factors Committee, expressed the view that we have not sufficient knowledge to justify addition of iron salts to flour at present, the principle of fortification of bread with a suitable ferrous or ferric salt has been officially accepted in the U.S.A. Nevertheless, there are many authorities who look askance at this and other proposals to add nutrients to flour.

For the amounts of "trace" elements in cereal products Sullivan[6] gives the following table:

TABLE IV

AN AVERAGE ANALYSIS OF THE ELEMENTS FOUND IN LESSER AMOUNT IN WHEAT, FLOUR AND BREAD

Constituent	Wheat ppm.	Patent flour ppm.	Bread ppm.
Zinc	100	40	50
Nickel	35	—	—
Iron	31	8	10
Manganese	24	3	8
Boron	16	4	3
Copper	6	2	5
Aluminium	3	0·6	—
Bromine	2	1	1
Iodine	0·006	0·004	—
Arsenic	0·1	0·001	—
Cobalt	0·1	—	—
Fluorine, vanadium, selenium, etc., present	—	—	—

Sullivan's figures for bromine were quoted from a paper by Damien and Blaignan[16]; since their work, the bromine content of flour, among various other foods, has been re-examined by Ford, Kent-Jones, Maiden and Spalding.[17] They found that the bromine content of wheaten flours, all guaranteed not to have received treatment with bromate, varied from 2·4 to 7·7 parts per million, and that of white breads from 1·6 to 5·4 parts ; a sample of wholemeal bread gave 6·5 parts.

Flour and bread contain calcium, although the proportion present is not very great. Their calcium contents cannot, however, be accepted as an index to the extent to which these foods contribute this mineral to the diet. The reason for this is that wheat contains phytic acid and this compound has the property of rendering calcium non-available to the human system. When the phytic acid is present in excess—as it is in wheatmeal and wholemeal, owing to the majority of the phytic acid in wheat being concentrated in the outer coverings—it may render non-available not only the calcium in that particular foodstuff but also calcium contained in other foods ingested at the same time. The significance of various breads in relation to calcium intake, therefore, depends upon the balance between their calcium and phytic acid contents and can only be assessed upon this basis. As pointed out recently by Widdowson[7] it is necessary to take into account the effect of baking on the phytic acid content of a flour, since a much lower proportion of the phytic acid initially present is destroyed in wheatmeal than in white flour during the baking process.

The calcium contents of white and wholemeal bread are given in the tables of McCance and Widdowson[1] and the phytic acid phosphorus contents can be calculated from the figures for total phosphorus by means of the table which shows the proportion of the phosphorus which is available. No figures for National 85 per cent. wheatmeal bread are given in McCance and Widdowson's tables, but the calcium and phytic acid phosphorus contents of the meal have been reported and from these and Widdowson's values for the phytic acid destroyed during the baking of 85 per cent. wheatmeal, the figures for the bread can be calculated. Figures for the calcium and phytic acid phosphorus contents of bread produced from white flour, National (85 per cent.) flour and wholemeal are given in Table V.

TABLE V

Bread	Calcium (mg. per 100 g.)	Phytic acid phosphorus (mg. per 100 g.)
White	23	4
National flour (85 per cent.) ..	27	26
Wholemeal	30	77

The quantity of calcium rendered non-available by phytic acid depends, of course, upon what salt of the acid is formed, and the problem is complicated by the fact that usually magnesium is also present in the compound. There are, however, indications that the proportion of calcium "fixed" by a given amount of phytic acid approximates either to a tri- or to a hexa- calcium salt. It is of interest to calculate from the figures of Table V the excess or deficit of calcium resulting from the ingestion of bread on each of these assumptions. The figures thus obtained are given in Table VI.

TABLE VI

Bread	Phytic acid Phosphorus (mg. per 100 g.)	Calcium (mg. per 100 g.) Total	"Fixed"	"Available" (+ or −)
A. (Assuming formation of tri-calcium salt)—				
White	4	23	3	+20
National flour	26	27	17	+10
Wholemeal	77	30	49	−19
B. (Assuming formation of hexa-calcium salt)—				
White	4	23	6	+17
National flour	26	27	34	− 7
Wholemeal	77	30	98	−68

Thus, white bread gives a positive balance of calcium whether the tri- or hexa- salt is formed, whereas wholemeal bread will, in any event, render non-available to the system not only its own calcium, but also some of that contained in other foods in the diet. National (85 per cent.) bread will give either a small positive or a small negative balance depending upon whether the tri- or hexa- calcium salt is formed in the body. To counteract any deficiency of calcium in the diet as a whole, it was decided to give the population extra calcium *via* its flour. To every sack of National flour (280 lb.) is added 7 oz. of calcium carbonate in the form of *Creta praeparata*. Table VII shows the effect of this addition to both white and National flour.

TABLE VII

Bread from	Calcium available (+ or −), mg. per 100 g. A (Assuming formation of tri-calcium salt)	B (Assuming formation of hexa-calcium salt)
White flour	+20	+17
White flour + $CaCO_3$, 7 oz. per sack ..	+65	+62
National flour	+10	− 7
National flour + $CaOC_3$, 7 oz. per sack	+55	+38

Bread as a source of vitamins.—Possibly the most important difference between white, National and wholemeal breads is in the vitamin contents Brown breads and, particularly, germ breads have more vitamin E than white bread, since wheat germ is a rich source. An important discovery of recent times is that there is no vitamin A or biologically active carotenoid in flour. This finding disposes of the argument against the bleaching of flour on the score that it has a destructive effect on the vitamin A potency. White bread has low contents of vitamin B_1 and the "vitamin B_2 complex," compared with wholemeal and wheatmeal bread. The following figures which allow for loss in baking may be taken as approximately correct. Incidentally, toasting may destroy up to 20 per cent. of the B_1.

TABLE VIII

Bread from	Vitamin B_1 (I.U. per 100 g.)	Riboflavin (mg. per 100 g.)	Nicotinic acid (mg. per 100 g.)
White flour (72 per cent.) ..	20	0·03	0·7
White flour (75 per cent.) ..	28	0·05	1·2
White flour + 0·2 g. aneurin per sack	61	0·05	1·2
National flour (85 per cent.)	65	0·12	3·0
Wholemeal (95 per cent.) ..	82	0·14	3·3

The figures for aneurine (vitamin B_1) are better founded than those for riboflavin and nicotinic acid. Recently, moreover, owing to an improved micro-biological method for assaying riboflavin in cereals and other products, Barton-Wright and Booth[14] have made possible the establishment of further figures for this vitamin. The chemical (fluorimetric) test for B_1 has been well tried out and frequently checked against biological assays by both the rat-growth and the bradycardia methods. While some reliance can now be placed upon the riboflavin figures, the nicotinic acid figures have hardly emerged from the experimental stages.

The greater the consumption of carbohydrates, the greater is the need for vitamin B_1. In view of the low amount of water-soluble vitamins in white bread and the large proportion of bread in the diet, especially of the poorer classes, serious criticism has been made of white bread. In fact, the plea of many nutritionists for the substitution of brown bread for white bread in the diet is largely based on this consideration. In the manufacture of white flour, the outer portions of the grain and of the germ, which are rich in these vitamins, are excluded. To meet this defect it has been proposed to fortify white flour by the addition of synthetic vitamin B_1. When 75 per cent. white flour was made, it was fortified by the addition of 0·2 g.

vitamins, are excluded. To meet this defect it is proposed to fortify white flour by the addition of synthetic vitamin B_1. When 75 per cent. white flour was made, it was fortified by the addition of 0·2 g.

aneurine a sack, which added to the existing 40 I.U.'s per 100 g.

a further 52 I.U.'s, bringing the total close to the 100 I.U.'s usual in 85 per cent. National flour.

The standards for enriched flour now in use in the U.S.A. are given below; the first four items are compulsory, the other two optional, though their addition must be declared.

TABLE IX

	Mg. per lb. of flour
Aneurine	1·1–2·2
Nicotinic acid	10–20
Riboflavin	0·6–1·2
Iron	8–16
Calcium	300–1200
Vitamin D	150–600 I.U.

It was suggested that a further amendment to this scheme might come into operation on 1st October, 1943, whereby the minimum level of enrichment would be:

	Mg. per lb. of flour
Aneurine	2
Nicotinic acid	16
Riboflavin	1·2
Iron	13

In connection with the simple fortification of white flour with aneurine, it should be remembered that, although Chick[8] has found in rat feeding experiments that white bread with additional vitamin B_1 was inferior to wholemeal, M. D. Wright[9] has since pointed out certain defects in Chick's work. Wright made her comparison between modern 75 per cent. flour fortified with 0·2 g. aneurine per sack and 85 per cent. wheatmeal and found that rats throve as well on the one bread as on the other. Further, on a mixed diet, such as might be consumed to-day by the poorer classes, rats thrive excellently, irrespective of whether the bread portion, comprising 35 per cent. of the diet, is fortified white (75 per cent.) or National wheatmeal (85 per cent.). H. C. H. Graves[18] has also questioned the validify of Chick's conclusions, and the matter must be regarded as still *sub judice.*

Finally, in reviewing the nutritive value of bread, mention must be made of a paper by Norman Wright[10] entitled "Wheatmeal Bread or Milk." Wright emphasized the importance of remembering the effect on milk supplies caused by the diversion of wheatfeed from dairy cows to direct consumption in bread. The proposal to increase the extraction rate of 85 per cent. did not, he claimed, result in any appreciable increase in nutrients for the population, which is one of the arguments normally put forward to support increased extraction in war-time. The subject is clearly one of great importance; an attempt to settle the questions involved must not be shirked because of their complexity and their inter-connection with other questions that are not nutritional at all, or even primarily scientific. One of us (A. L. B.) has already discussed elsewhere[11] Dr. Wright's contribution to the subject, and has ventured to make certain corrections and additions to his figures and conclusions. There would seem to be no doubt upon certain facts. Retention of wheat feed in bread, and any consequent diversion from the feed of milch cattle, involves losses of protein, calories, available calcium, and riboflavin. On the other hand, it involves gains of iron, aneurine, and nicotinic acid. The extent of these losses depends, naturally, upon the true values for the relative availability of calories and protein in high extraction flour and wheat feed, as well as on the relative values for the amounts of available calcium, iron, and vitamins in the different portions of the wheat grain. As has been made clear in this paper, there must be some element of doubt about certain of these, such as calcium, riboflavin and nicotinic acid. Nevertheless, we believe the summary of the position given in this paragraph to be a fair statement of facts, upon which all parties in this controversy may agree.

When it comes to deciding which set of nutrients is the more valuable of the two, it is clear that no answer can be given in terms of nutrition only. A given amount of riboflavin cannot, for example, be equated in terms of nutrition to a specific amount of aneurine ; they are different substances, have different physiological effects and cannot replace one another. The policy of determining the proportions of wheat feed that are to proceed directly or indirectly into the human stomach must involve considerations external to the field of nutrition and therefore to the subject of this paper. But knowledge and understanding of the facts to which we here allude is essential to any nationally sound solution of the problem in question.

Whether or not wheat offals constitute an important item in the diet of milch cows has received considerable discussion. It appears to be determined to a large extent by the nature and amount of imported feeding-stuff, in turn determined—as we know well from war-time experience—by many factors. It is, however, clear that wheat offals are of great value in the feeding of pigs and poultry and the considerations just set out must also bear on any just evaluations of their claims to this part of the wheat grain.

Conclusion

The great value of bread, whether white (particularly modern white bread fortified with vitamin B_1) or "brown" (particularly 85 per cent. flour, which has most of the virtues of wholemeal but is more attractive) is clear, as is the important place of bread in the national diet. Bread provides over 20 per cent. of the total calories of the diet and also more than 20 per cent. of the protein. Together with other wheaten products (home-made bread, cakes, biscuits, puddings, etc.) it provides 35 per cent. of the calories of the Nation's diet, and 35 per cent. of the protein consumption. Bread made from 85 per cent. extraction flour will also provide the nation with 45 per cent. of its B_1 requirement.

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CHAPTER XV

THE CHEMICAL COMPOSITION AND NUTRITIVE VALUE OF MAIZE, RICE, RYE AND BARLEY

By W. P. Ford

An attempt is made in this chapter to deal with four cereals that take an important place in the food of mankind, although in this country they form a very small part of the diet compared with wheat.

World production figures for these four cereals are given in Table I. Maize and rice are second only to wheat, whereas rye and barley, approximately equal to one another in tonnage, show about one-half the figure for rice. The proportions in which these cereals are used in Great Britain are, however, entirely different, maize coming well to the fore and rice and rye falling very far behind. Most of the maize and one-half of the barley are, however, used for animal feeding, and almost all of the other half of the barley is used by brewers or distillers, thus further reducing the importance of these cereals relative to wheat as human food.

MAIZE

Maize had its origin in America but, as it is easy to grow in a warm climate which also has a fairly good rainfall, its cultivation has spread to Africa, India, Australia and the warmer part of Europe. Nevertheless, more than one-half of the world's crops is still grown in the U.S.A., where it is easily the chief cereal crop and is known as "corn." The chief types are dent corn (*Zea indentala*) and flint corn (*Zea indurata*). A good sample of maize should have 95 per cent. to 98 per cent. sound grain. The skin of the grain and the germ constitute about 27 per cent., and the remaining 73 per cent. is the starchy endosperm. The germ is approximately 8 per cent. to 10 per cent. of the whole; being very oily it is often removed to prevent the development of rancidity. The chemical composition of the bran, germ, and endosperm of a high protein maize are shown in Table II, from Kent-Jones' *Modern Cereal Chemistry*, 1939,[1] and further analyses of maize given by C. D. Woods[2] are shown in Table III. Maize contains less ash than wheat, and is notably deficient in calcium, magnesium, iron, and phosphorus compared with wheat (see Table IV).[3] The oil content is high compared with the other cereals, owing to a large embryo rich in oil. This is a feature which must be remembered in using maize for animal feeding; too much maize in the ration lowers the melting point of the animal's own fat. The amount of fibre is low and the carbohydrates are easily digested, especially as maize for animal and poultry feeding is often steamed and flaked, which partially gelatinizes the starch.

TABLE I

	World production average 1931–1935	Imports into Gt. Britain average 1931–1936	Home production	Home consumption
Maize	99,500	3500	Nil	3500
Rice (cleaned)	89,000	116	Nil	116
Rye	45,000	4·3	Nil	4·3
Barley	41,000	750	750	1500
Oats	62,000	180	2100	2280
Wheat	145,000	5300	1500	7700
Wheat flour		300		
Wheat offals		600		

All figures are in thousands of tons.

The principal protein of maize is zein, which is deficient in both tryptophan and lysine and consequently has a low biological value, but maize glutelin, the other important maize protein, is not deficient in these amino-acids. Some of the classical experiments by Osborne and Mendel[4] on the effect on rat growth of certain essential amino-acids were carried out with zein and showed tryptophan and lysine to be lacking in a diet with zein as the only protein. Probably the striking results of these early experiments have given a bad name to maize protein which has stuck to it ever since, but Boas Fixsen[5] finds that there is scarcely anything to choose between the nutritive values of whole maize and whole wheat proteins, and the same conclusion was reached by Hoagland and Snider[6] when using 2 parts of the cereal protein in conjunction with 1 part of beef protein. The effect of storage of both whole and ground maize on the nutritive value and other properties of the protein over periods ranging from 6 months to 2 years, has been studied by Jones, Divine and Gersdorff.[17]

The reputed low nutritive value of maize proteins was at one time thought to be the cause of the deficiency disease, pellagra, as this occurs where the diet is poor and maize is a major constituent. It is now known that pellagra can be prevented by the inclusion of nicotinic acid in the food, but obviously a more satisfactory nutritional solution is a better balanced diet containing more animal protein, not a mere nicotinic acid supplement. Maize contains as much vitamin B_1 as other cereals. From an examination of 23 samples, Schultz, Atkin and Frey[7] give a range of 140 I.U. per 100 g. to 200 I.U. per 100 g. with no significant difference between the white and yellow varieties. Also these two varieties are similar in their content of riboflavin and nicotinic acid. Riboflavin varies from 80 μg/100 g. to 230 μg./100 g. with an average of 130 μg.[18] Nicotinic acid values of 3·17 mg./lb. are given for yellow maize and 3·35 mg./lb. for white maize by Thomas, Bina and Brown.[19] On the other hand, yellow maize is reported to contain from 200 μg. to 900 μg. of carotene per 100 g., whereas the white variety contains none.

TABLE II

CHEMICAL COMPOSITION OF MAIZE

	Hull Per cent.	Embryo Per cent.	Endosperm Per cent.
Protein	6·6	21·7	12·2
Ash	1·3	11·1	0·7
Fat	1·6	29·6	1·5
Carbohydrates (N.F.E.)	71·1	34·7	85·0
Crude fibre	16·4	2·9	0·6

TABLE III

CHEMICAL COMPOSITION OF MAIZE

Kind of material	Water Per cent.	Protein Per cent.	Fat Per cent.	Starch, etc. Per cent.	Crude fibre Per cent.	Mineral matter Per cent.
Corn (whole grain av.) ..	10·8	10·0	4·3	71·7	1·7	1·5
Corn (low N content) ..	10·5	6·0	3·8	78·5	—	1·2
Corn (high N content) ..	10·5	12·9	4·4	70·8	—	1·4
White corn	11·4	10·8	5·0	68·8	2·5	1·5
Yellow corn	11·9	10·7	4·8	68·9	2·2	1·5
Sweet corn (matured) ..	8·8	11·6	8·1	68·8	2·8	1·9
Pop corn	10·7	11·2	5·2	69·6	1·8	1·5
Corn meal (whole grain) ..	12·0	8·7	4·7	71·1	2·2	1·3
Corn meal (granulated) ..	12·5	9·2	1·9	74·4	1·0	1·0
Cornflour (bolted)	12·6	7·1	1·3	77·5	0·9	0·6

In Great Britain the maize product best known to the general public is probably cornflour, which is used in custard, blanc-mange, and baking powders. It is practically pure maize starch and is more correctly described by the American term "corn starch."

As so much of the imported maize is used for animal feeding, it may not be out of place to consider its value for this purpose. The main points in its favour are that it is a concentrated, easily digested and palatable food. It is therefore useful for fattening cattle and pigs and for cows in milk and poultry when laying. Flaked maize or maize meal may constitute 15 per cent. to 25 per cent. of the ration, but mineral and protein supplements are necessary, and for cows fibrous food as well. Maize germ meal and maize gluten are two other maize products used for animal feeding. The first is the residue after oil has been pressed from maize germ, and the latter is defined in the Fertilizers and Feeding Stuffs Act, 1926, as "a by-product resulting from the removal of starch and germ from maize, to which no other matter has been added." Analyses given in *Rations for Live Stock*[8] (*Bulletin* 48) issued by the Ministry of Agriculture are:

	Maize germ meal	Maize gluten feed	Maize gluten meal
Moisture	10·8	10·4	9·1
Protein	13·0	23·5	35·5
Oil	12·5	3·4	4·7
Soluble carbohydrate	56·0	56·7	47·5
Fibre	4·1	3·5	2·1
Ash	3·6	2·5	1·1

TABLE IV

INORGANIC CONSTITUENTS OF CEREAL FOODS

					Mg. per 100 g.				
	Na	K	Ca	Mg	Fe available	Cu	P	S	Cl
Barley (pearl)	2·6	123	9·7	20·2	0·67	0·12	206	107	105
Cornflakes	(1050)	114	7·4	16·5	2·8	0·09	58	92	(1520)
Rice (polished)	6·3	113	3·7	13·1	0·38	0·06	99	78·5	27
Ryvita	(615)	469	40·5	90·7	3·73	0·15	295	87	(935)
Wholemeal flour	160	324	28·8	101	2·96	0·38	245	123	177
White flour	29·5	144	18·4	23·7	0·85	0·07	102	108	67·5

RICE

Rice is the cereal of the swamp. It needs plenty of sunshine and water, and is extensively grown in India, Burma, China, and Japan, where it is one of the staple foods. Rice when threshed is known as "paddy" and is covered with a fibrous husk comprising nearly 40 per cent. of the grain. The husk has a high percentage of ash (18 per cent. to 20 per cent.), consisting largely of silica. This husk is removed by rough grinding and winnowing, but the rice is still covered with a brown skin, which is taken off, together with the germ, by scouring and polishing. The bran skin, germ, some husk, and endosperm constitute a by-product known as rice meal, which is used for animal feeding, and it is interesting to note that the imports into Great Britain of this by-product during 1931–36 were twice as great as the amount of rice itself.

Table V[1] shows the composition of two types of rice at different stages of milling. With the removal of the husk there is a very big decrease in the percentages of fibre and ash and also in the percentage of oil when the germ is removed with the skin. More important, however, to peoples to whom rice is a staple food is the loss of vitamin B_1 on milling. Polished rice is attractive to look at and is undoubtedly a good source of carbohydrate, but it is a poor food from the nutritional point of view. The story of the recognition of beri-beri as a vitamin B_1 deficiency disease has been so well told by Harris[9] in the first volume of *Vitamins and Vitamin Deficiencies*, 1938, that there is no need to repeat it here. The result of including rice polishings in the diet of persons subsisting largely on white or polished rice is little short of miraculous. A product of good appearance with better nutritional value is obtained by soaking and steaming the rice before milling, by which means sufficient of the B_1 in the skin is washed into the endosperm to prevent the occurrence of beri-beri in persons living on the resultant polished rice. This is known as "parboiled" or "cured" rice and its value compared with ordinary polished rice was demonstrated by Fletcher.[10]

TABLE V

CHEMICAL COMPOSITION OF RICE

Description of product	Moisture	Fat	Protein	Starch (by diff.)	Crude fibre	Ash
Honduras—	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Unhusked rice ..	11·27	1·58	7·48	65·60	8·67	5·40
Husked rice ..	12·32	1·79	8·57	75·15	0·99	1·18
Skinned rice ..	12·50	0·28	7·88	78·57	0·30	0·47
Polished rice ..	11·89	0·25	8·06	79·14	0·30	0·36
Japanese—						
Unhusked rice ..	11·50	1·74	6·50	66·19	7·93	5·14
Husked rice ..	12·38	1·52	7·24	76·88	0·85	1·13
Skinned rice ..	13·38	0·31	6·59	79·03	0·29	0·40
Polished rice ..	12·82	0·22	6·61	79·74	0·29	0·32

	No. of patients	Cases of beri-beri	Deaths
Diet mainly polished rice ..	120	36	18
Diet mainly "cured" rice ..	123	2	0

The protein of rice seldom exceeds 8 per cent. and is thus low compared with that of other cereals. The chief protein is oryzenin —a glutelin soluble in dilute alkali—together with small quantities of a globulin and an albumin. Unlike the other cereals rice contains no alcohol-soluble protein. In a recent series of papers on "The Nutritive Value of the Proteins of Rice," M. C. Kik[11] has shown that the percentages of tryptophan, arginine and histidine in rice protein compare favourably with the amounts in wheat or maize proteins, but there is much less lysine in rice than in wheat and the cystine content is also lower. It would seem possible to increase the amount of lysine by 33 per cent. through selection of a variety richer in lysine and also by 33 per cent. to 50 per cent. on manuring with sulphur at 2000 lb. per acre, but rice would still remain poor in lysine. The inorganic constituents of rice are also poor, the quantity of ash in polished rice being low and the amounts of calcium, magnesium, and iron very low, even by comparison with white wheaten flour (see Table IV). One is forced to the conclusion that, except as a source of easily digestible carbohydrate, polished rice is from the nutritional point of view the least valuable of the cereals.

Barley

The barley used in this country is almost equally divided between the maltster and the farmer. Only a very small amount is used directly as human food. Barley when converted into malt is used principally in the production of beer, spirits, vinegar, and yeast for bakers, and there is also a demand for malt flour and malt extract for bread-making and for medicinal preparations such as malt extract with fish-liver oils. The selection of varieties of barley suitable for malting and brewing has been the subject of much experiment in all countries where beer is popular, but many factors are involved in addition to the chemical composition. Generally a barley with 8 per cent. to 10 per cent. of protein is preferred. The right barley for the right beer is, however, a subject with which I do not propose to deal here. Barley for grinding into barley meal as a feeding stuff for animals is more valuable if it is dry and has a higher percentage of protein, say 11 per cent. to 12 per cent., such as is found in Canadian and American barleys. A high protein barley also gives a more diastatic malt.

TABLE VI

Chemical composition of barley

Type of barley	Water Per cent.	Protein Per cent.	Fat Per cent.	Starch, etc. Per cent.	Fibre Per cent.	Ash Per cent.
English (Warrington)	14·3	10·6	2·1	66·0	4·5	2·5
German (Kellmer)—						
Medium ground ..	14·3	9·4	2·1	67·8	3·9	2·5
Large ground ..	14·3	8·7	1·8	70·2	2·7	2·3
Flat ground ..	14·3	10·2	2·5	63·7	5·0	2·8
Feeding	14·3	12·0	2·4	63·7	5·0	2·6
American (Wiley) ..	10·85	11·0	2·25	69·55	3·85	2·50

The chemical composition of several barleys is given in Table VI, taken from Kent-Jones' *Modern Cereal Chemistry*, 1939. It shows that barley is very similar in composition to wheat, the chief differences being that barley contains twice as much fibre, about 0·7 per cent. more ash, and 2 per cent. to 3 per cent. less protein. The proteins of barley are stated by Hopkins and Krause[12] to be leucosin (albumin) 0·35 per cent., edestin (globulin) 2·8 per cent., hordein (prolamin) 3·25 per cent., and a glutelin 2·6 per cent. These figures relate to whole barley, but there is no need to differentiate between the various parts of the barley grain, because generally the whole grain is employed. An exception to this is "pearl barley" which has been largely freed from bran by scouring. The ash is by this process reduced from 2·5 per cent. to between 0·7 and 1·1 per cent.

In the paper already referred to, Schultz, Atkin and Frey[7] give vitamin B_1 figures on 37 samples of American barley as 127 I.U. to 307 I.U. per 100 g. with an average of 207 I.U. per 100 g. and this corresponds closely to the values given by these workers for wheat, maize, and rye. Pearl barley contains only one-tenth of the B_1 in the whole grain. The riboflavin in barley is reported as 105 μg. per 100 g. to 150 μg. per 100 g. by Andrews, Boyd and Terry[20] and the nicotinic acid as 1·5 mg. per 100 g. by Thomas, Bina and Brown.[19] Finally, barley is sold for making barley water or as groats for use in infant feeding to prevent a thick curd from milk being precipitated in the stomach. Also plenty of barley water has a cooling effect in fevers and a soothing effect when the digestive organs are deranged, but any usefulness of barley for these purposes is not related in any known way to its chemical composition.

Rye

Rye is the cereal of eastern Europe ; 95 per cent. of the area under rye is in Europe, 57 per cent. is in Russia, and large quantities are grown in Germany and Poland where the soil is poor and sandy and, therefore, unsuitable for wheat. Sir Wm. Ashley's *Bread of our Forefathers* states that rye was still an important part of the cereal crop in England in 1764. North of the Humber 30 per cent. of rye was used for bread and in Wales as much as 42 per cent. Rye has long been entirely displaced by wheat as a bread cereal in Great Britain, but efforts are now being made to re-establish it as a British crop.

In chemical composition rye is similar to wheat, although in general it contains less protein. There is a wide variation in protein content, from 6 per cent. to 13 per cent., the more proteinous ryes being Canadian, Russian, and Plate. There is also a very marked decrease in protein as the grade of flour is increased, the pure endosperm flour being very low in protein. This is shown by figures for rye flours of different extraction published by Fornet[13] (Table VII).

The protein of rye contains gliadin, identical with wheat gliadin, and also albumin, globulin, and glutelin. The proportion of gliadin increases as more of the bran is excluded and rises to 50 per cent. in the whitest flours made from pure endosperm. The proteins of rye are more soluble in water and in salt solutions than the proteins of wheat, as much as one-third of the rye protein dissolving, whereas in wheat seldom more than 15 per cent. of the protein is water soluble. Rye flour is darker in colour than wheat flour of the same extraction and also has a slightly higher ash percentage. It has been stated that the ash of rye contains more magnesium and less calcium than the ash of wheat, but the figures given by McCance and Widdowson[3] (Table IV) for whole meal flour and Ryvita do not bear this out. Unfortunately, it cannot be assumed that the wholemeal flours referred to were genuine whole wheat flours, for they were obtained from shops and in common parlance "wholemeal" is a general name for almost any brown flour, which may contain anything from 80 per cent. to 100 per cent. of the wheat. The same authors found more iron in rye but less copper.

TABLE VII

COMPOSITION OF RYE PRODUCTS

Kind of material	Ash Per cent.	Fat Per cent.	Protein Per cent.	Sugar Per cent.	Starch Per cent.	Fibre Per cent.
No. 1 flour (0–30) ..	0·46	0·69	6·70	4·65	81·53	0·07
No. 2 „ (30–60) ..	0·94	1·43	11·00	7·18	69·44	0·40
No. 3 „ (60–65) ..	1·74	2·29	14·47	8·98	60·27	0·93
No. 4 „ (65–70) ..	2·09	2·71	16·58	11·45	55·40	1·22
Bran (70–95)	4·83	3·62	17·58	12·96	20·49	5·79
Germ	5·54	11·95	44·74	22·62	—	3·94

The amount of vitamin B_1 in rye is of the same order as in wheat. Schultz, Atkin and Frey[7] give a range for ten samples of American rye from 130 I.U. per 100 g. to 190 I.U. per 100 g., and Baker and Wright,[14] using the bradycardia method, found a value for rye germ (750 I.U. per 100 g.) within the range given for wheat germ. Values for riboflavin and nicotinic acid given in the literature (Andrews, Boyd and Terry,[20] and Thomas, Bina and Brown[19]) are 130 μg. per 100 g. to 165 μg. per 100 g. and 0·97 mg. per 100 g. respectively. The percentages of sucrose and of reducing sugars are two to three times greater in rye flour than in wheat flour, but the sugar produced during an autolytic digestion of the flour, under the conditions used for the maltose figure of wheat flour, is of the same order as for wheat flour, viz., 1·5 per cent. to 3·0 per cent.

Rye bread is the most common type of bread in Germany and many other European countries, but it is often made with an admixture of 15 per cent. to 30 per cent. of wheat flour. Wheaten bread was also made in western Germany with an admixture of 30 per cent. rye flour, and rye bread referred to in American publications generally contains no more than 33 per cent. rye flour. The bread is darker than wheaten bread, closer and heavier, and more acid. Except with mixtures containing more than 50 per cent. of wheat, yeast is not used for aerating the bread as the sour dough process is more suitable. The acidity produced by the bacteria and yeast of the sour dough during a fermentation process which extends over 24 hours is very helpful in building up a satisfactory load; if yeast is used, it is advisable to acidify the dough by the addition of an acid, such as tartaric.

TABLE VIII

DIGESTIBILITY OF BREAD FROM WHEAT AND RYE MEALS

Extraction of flour or meal Per cent.	Wheat		Rye	
	Percentage digested			
	Dry material	Protein	Dry material	Protein
0–70 ..	95·6	87·1	92·8	76·1
0–85 ..	89·6	82·2	87·5	68·8
0–94 ..	86·8	75·0	84·0	61·3
0–100 ..	85·4	74·4	82·9	59·5

Comparative tests on the digestibility of wheat bread and rye bread show a slight advantage in favour of wheat, especially in the utilization of the protein, but this may be to some extent accounted for by the greater amount of bran in rye flour compared with a wheat flour of the same extraction. The darker and coarser kinds of rye bread are certainly not so well utilized as corresponding wheaten breads, or as rye breads from finer flour. This is illustrated by figures (Table VIII) in Neumann's *Brotgetreide und Brot.*, 1929. These conclusions are confirmed by Laug, Garavelli and Nash[15] working with phloridzinized dog, and French and Mattill[16] working with young rats. As rye also contains less protein than wheat, it is probable that British white bread supplies more digestible protein than German rye bread.

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CHAPTER XVI

THE CHEMICAL COMPOSITION AND NUTRITIVE VALUE OF OATS AND OATMEAL

By H. C. Moir

It is alleged that Dr. Johnson once proposed to state in his famous dictionary that oats are used in England as food for horses and in Scotland as food for men ; to which proposal, Boswell retorted "And where, sir, will you find better horses than in England or better men than in Scotland?" The position of oats is defined by determinations of its chemical composition ; the data to be found in the literature are mostly for raw oats and it is obvious that the authors were more concerned with animal than human nutrition.

Proximate analysis.—In Table I are shown analyses of whole oats from various places, as given by various authorities. In common with all other plants, oats vary in composition with variety, climate, manurial treatment and so on, and the wide variation is shown in the table. Table II gives analyses of the hulled grain or groats. The milling process for oats consists essentially of cleaning, drying, hulling, and size reduction, the hulled oat being cut rather than ground to the desired size. Groats as such are seldom used directly as food, and the following Tables III, IV, and V give in an accessible form the information on the proximate composition of the oat products most commonly used. To complete the story, Table VI gives the proximate composition of the products obtained on one mill from one grist, in this instance a blend of oats of several varieties, chosen so as to keep the quality of the oatmeal uniform. To obtain a true picture of the variations, the results in Table VI have been calculated to the moisture-free basis in Table VII. It will be noted that there is a tendency for the finer products to be poorer in protein and fat than the coarser products. I am unable to explain why this should be so, but examination of Tables II, III, IV, and V reveals the same tendency. The tendency is not great, and

TABLE I

Proximate composition of whole oats

Authority	Source or variety	Moisture	Protein (N × 6·25)	Fat (ether extract)	Carbo-hydrates	Cellulose (crude fibre)	Ash
Hutchison[3]	—	10·0	10·9*	4·5	59·1	12·0	3·5
Bennion[4]	—	13·28	14·81	4·36	53·02	11·82	2·71
Berry[5]	—	13·40	9·46	5·33	60·23	8·96	2·62
Dyer[6]	English	15·97–9·97	14·30–8·65	5·86–3·32	63·02–53·29	11·90–6·80	3·78–2·57
	Plate	11·53–9·73	7·40–6·50	10·20–8·90	61·04–57·97	10·90–7·98	4·20–3·80
	Canadian	10·73–10· 0	5·43–5·25	12·75–12·70	61·27–61·10	7·55–7·02	3·17–3·03
	Chilean	10·30	7·30	10·20	62·49	6·51	3·20
Brownlee and Gunderson[1]	American	10·06	12·15	4·33	57·93	12·07	3·46
Dodd and Telford[8]	English A	8·25	12·16	6·72	56·27	12·80	3·80
	„ B	9·00	13·25	5·95	57·25	10·65	3·90
	Plate	8·35	11·56	7·57	59·76	8·90	3·86
	Canadian	10·95	12·94	5·07	58·23	9·40	3·40
Lewis[9]	Cape (Av. of 52)	9·85	9·53	6·03	60·77	10·20	3·62
Winton and Winton[2]	European	8·31	11·63	5·86	59·79	10·80	3·61
Aitken[12]	Scotch	16·9	11·57	5·59	57·54	8·25	2·59
Moir	Raw Scotch	15·20	7·75	5·10	61·03	8·25	2·67
	Kiln dried Scotch	5·10	11·10	5·86	65·83	9·36	2·75
	Victory (thin skinned Aberdeenshire)	14·10	9·90	4·90	60·00	8 43	2·67
	Yielder (thick skinned Aberdeenshire)	14·00	10·80	4·80	58·06	9·98	2·36
Overall variation (omitting kiln dried)	Maximum	16·9	14·81	12·75	63·02	12·80	4·20
	Minimum	8·25	5·75	4·33	53·02	6·51	2·57

* N × 5·7

TABLE II

PROXIMATE COMPOSITION OF HULLED OATS (GROATS)

Authority	Source or variety	Moisture	Protein (N × 6·25)	Fat (ether extract)	Carbo-hydrates	Cellulose (crude fibre)	Ash
Hutchison[3]	—	6·9	13·0*	8·1	68·6	1·3	2·1
Berry[5]	—	13·40	12·34	7·73	63·47	1·33	1·83
Brownlee and Gunderson[1]	American	6·93	14·31	8·14	67·09	1·38	2·15
Plimmer[10]	—	7·7	12·0	8·4	68·3	1·6	—
Winton and Winton[2]	—	8·04	18·37	6·26	62·02	2·80	2·51
Moir	Scotch	6·50	14·50	6·59	69·78	0·79	1·84
Variation	Maximum	13·40	18·37	8·14	69·78	2·80	2·51
	Minimum	6·50	12·0	6·26	62·02	0·79	1·83

* N × 5·7

TABLE III

PROXIMATE COMPOSITION OF OATMEALS

Authority	Source or variety	Moisture	Protein (N × 6·25)	Fat (ether extract)	Carbo-hydrates	Cellulose	Ash
Hutchison[3]	—	7·2	14·2*	7·3	65·9	3·5	1·9
	Scottish	5·0	14·6*	10·1	65·1	3·1	2·1
	Irish	5·0	13·4*	8·8	68·4	1·7	2·0
Dyer[7]	Fine	9·53–8·20	18·19–12·94	12·83–8·60	66·31–54·40	2·20–1·10	4·03–1·77
	Coarse	9·17–7·93	15·46–13·06	10·23–8·73	65·25–64·51	1·13–0·87	1·97–1·77
Plimmer[10]	Coarse	7·0	12·3	8·2	69·9	0·8	—
	Medium	6·9	11·9	8·6	70·0	0·8	—
	Fine	8·2	11·7	8·3	69·3	0·7	—
Sherman[11]	—	7·3	16·1	7·2	67·5	0·9	1·9
Moir	Scotch pinhead	7·2	14·9	6·54	68·88	0·66	1·82
	medium	8·80	12·20	6·50	70·08	0·75	1·67
	midcut	6·60	13·00	6·61	71·49	0·54	1·76
	fine	7·70	12·70	6·00	70·59	1·29	1·72
	Biscuit, fine	8·30	13·70	7·02	67·93	1·05	2·00
Variation	Maximum	9·53	18·19	12·83	71·49	3·5	4·03
	Minimum	5·0	11·70	6·00	51·40	0·54	1·67

* N × 5·7

TABLE IV

PROXIMATE COMPOSITION OF ROLLED OATS, OAT FLAKES

Authority	Source or variety	Moisture	Protein (N × 6·25)	Fat (ether extract)	Carbo-hydrates	Cellulose (crude fibres)	Ash
Hutchison[3]	—	7·2	15·4*	7·2	64·8	3·5	1·9
	Quaker	7·8	14·7*	6·2	69·8†	—	1·5
Dyer[7]	—	9·27–8·17	15·18–12·68	9·30–7·53	67·02–65·24	1·17–0·80	1·90–1·67
Brownlee and Gunderson[1]	—	7·7	16·7	7·3	66·2	1·3	2·1
Plimmer[10]	—	8·5	13·1	6·5	69·5	0·7	—
Winton and Winton[2]	—	8·40	16·04	6·79	65·57	1·45	1·75
Moir	Scotch	8·50	14·50	6·60	67·25	0·91	1·84
Variations	Maximum	9·27	16·7	9·30	69·5	3·5	2·1
	Minimum	7·2	12·68	6·2	64·8	0·7	1·5

TABLE V

PROXIMATE ANALYSIS OF OAT FLOUR

Authority	Source or variety	Moisture	Protein (N × 6·25)	Fat (ether extract)	Carbo-drates	Cellulose (crude fibre)	Ash
Hutchison[3]	—	5·8	10·0	5·0	77·9†	—	1·3
Moir	Scotch	7·7	11·7	6·0	72·29	0·92	1·39

* N × 5·7. † Includes cellulose.

TABLE VI

PROXIMATE COMPOSITION OF OAT PRODUCTS FROM SAME GRIST

Source or variety	Moisture	Protein	Fat (ether extract)	Carbo-hydrates	Cellulose (crude fibre)	Ash	Vit. B_1 I.U./100 g.	pH at 20° C.
Scotch raw oats	15·20	7·75	5·10	61·03	8·25	2·67	70	6·02
Kiln dried oats	5·10	11·10	5·86	65·83	9·36	2·75	80	6·11
,, ,, groats ..	6·50	14·50	6·59	69·78	0·79	1·84	110	6·09
Pinhead oatmeal.. ..	7·20	14·90	6·54	68·88	0·66	1·82	120	6·08
Breakfast oat flakes ..	8·50	14·50	6·60	67·25	0·91	1·84	120	6·22
Medium oatmeal ..	8·80	12·20	6·50	70·08	0·75	1·67	120	6·05
Fine oatmeal	7·70	12·70	6·00	70·59	1·29	1·72	120	6·05
Oat flour	7-70	11·70	6·00	72·29	0·92	1·39	100	6·02

TABLE VII

PROXIMATE COMPOSITION OF OAT PRODUCTS FROM SAME GRIST ON MOISTURE-FREE BASIS

Source or variety	Protein	Fat (ether extract)	Carbohydrates	Cellulose (crude fibre)	Ash	Vit. B_1 I.U./100 g.
Raw oats	9·14	6·00	72·02	9·7	3·14	82
Kiln dried oats	11·70	6·20	69·40	9·8	2·90	84
,, ,, groats ..	15·50	7·00	74·69	0·84	1·97	120
Pinhead oatmeal.. ..	16·00	7·00	74·33	0·71	1·96	130
Breakfast oat flakes ..	15·80	7·20	74·00	0·99	2·01	130
Medium oatmeal ..	13·4	7·10	76·85	0·82	1·83	130
Fine oatmeal	13·7	6·50	76·54	1·40	1·86	130
Oat flour	12·7	6·50	78·31	0·99	1·50	110

for most purposes the composition of any oatmeal or flour in this country could be taken without serious error as—

	Per cent.
Moisture	8
Protein	14
Fat	7
Carbohydrate	68
Fibre	1
Ash	1·7

This analysis would give a calorific value of 3·91 cal. per g. or about 1,770 cal. per lb.

Moisture.—In common with that of other cereal products the moisture content of oatmeals varies with the relative humidity of the surrounding atmosphere.

Protein.—Osborne[13] separated the protein of oats into: (*a*) fraction soluble in weak alcohol; a prolamine (gliadin) amounting to 1·25 per cent. of the grain; (*b*) salt-soluble fraction; a globulin (avenalin) amounting to 1·5 per cent. of the grain; (*c*) insoluble fraction (remainder); a glutelin (avenin), analogous to glutenin of wheat. Lüers and Siegert[14] give a more complete separation into (*a*) an albumin, (*b*) a globulin soluble in 1·0 per cent. cold NaCl, (*c*) a globulin soluble in 10 per cent. NaCl solution at 65° C., (*d*) a prolamine, (*e*) a glutelin.

TABLE VIII

ULTIMATE ANALYSIS OF PROTEINS OF OATS

	Globulin (Avenalin)	Gliadin	Glutelin (Avenin)	Glutelin
Analyst		Osborne[13]		Csonka[15]
C per cent.	52·19	53·01	53·56	52·60
H ,,	7·00	6·91	7·09	6·56
N ,,	17·86	16·43	16·20	17·53
S ,,	0·65	2·26	0·90	0·81
O ,,	22·30	21·39	22·25	—
P ,,	—	—	—	trace
Ash ,,	—	—	—	0·28

Jodidi[16] reports the total nitrogen of oven-dried oats as 1·50 per cent. to 2·54 per cent. Of this nitrogen he states that 1·65 per cent. to 2·48 per cent. of the total is amino-acid N, 1·45 per cent. to 1·95 per cent. is acid amide N and 2·15 per cent. to 4·10 per cent. is peptide N. Lüers and Siegert[14] state that the alcohol-soluble portion of the protein has a high cystine content compared with other cereals; the globulins have less arginine and more non-amino nitrogen than the globulins of other cereals and avenalin, the characteristic protein of oats, is rich in arginine and histidine. Abderhalden and Hamalainen[17] state that they found in the glutelin, avenin, the amino-acids listed in Table IX; these account for 52·8 per cent. of the avenin.

TABLE IX

	Per cent.
Glycocoll	1·0
Alanine	2·5
Valine	1·8
Leucine	15·0
Aspartic acid	4·0
Glutamic acid	18·4
Tyrosine	1·5
Phenylalanine	3·2
Proline	5·4

Csonka gives a further analysis, shown in Table X, accounting for a further 34·93 per cent. of the avenin, if we assume the identity of the proteins analyzed by the two observers, though it is probable that they used different methods of extraction. Jones, Gerdorff and Moeller[18] give the cystine content of avenin as 3·48 per cent.

TABLE X

	Per cent.
Cystine	2·99
Arginine	8·33
Lysine	4·98
Histidine	2·26
Ammonia	16·37

More recently Csonka[19] states that the nitrogen of the oat is distributed as shown in Table XI.

TABLE XI

Amino-acid content and total N in moisture-free oat products

	Cystine Per cent.	Tryptophan Per cent.	Tyrosine Per cent.	Arginine Per cent.	Histidine Per cent.	Lysine Per cent.	Total N Per cent.
Whole oats (commercial)	0·079	0·055	1·03	0·516	0·123	0·186	2·22
Flaked oats	—	0·274	0·54	0·724	0·234	0·205	2·95

He draws attention to the increased content of tryptophan, histidine and lysine in the flaked oats compared with the whole oat. Qualitative expressions are used by Lo,[20] who states that in animal feeding experiments the protein quality of oats was satisfactory. Hartwell[21] states that the proteins of oatmeal are of good value for growth in rats.

Fat.—The fat or oil of oats has received very little attention and Table XII gives the information available about the constants of extracted oat oil, as summarized by Ball.[22]

TABLE XII

CONSTANTS OF OAT OIL

	Stellwaag 1890 seeds	Moljawsko Wezotski 1894 seeds	Dubovitz 1913 shelled	Pau 1921 seeds
Oil—				
Specific gravity	—	0·852	0·9110 15°/15°	0·925 15°/15°
Refractive index	—	1·4706 (15°)	—	1·4701 (40° C.)
Melting point	20° C.	—	—	8° C.
Saponification No.	184·2	—	180·13	189·8
Iodine No.	—	62·8	91·73	114·2
Reichert Meissl No.	—	0·9	—	—
Unsaponifiable per cent.	2·11	—	1·61	1·13
Fatty acids—				
Mean molecular wt.	278	—	—	284·8
Iodine No.	—	93·1	—	127·1
Melting point	—	—	—	27·5° C.
Refractive index	—	—	—	1·4635
Insol. fatty acids	92·8	—	—	93·6

Amberger and Wheeler Hill[23] report that the fatty acids present consist of:

	Per cent.
Palmitic	10·4
α-Linoleic	17·2
β-Linoleic	13·9
Oleic	58·5

They also remark that erucic and linolenic acid were not found, Diemuir, Bleyer and Schmidt[24] report the presence of an α-lecithin. the fatty acids present being palmitic, stearic, linoleic, and traces of oleic.

Carbohydrate.—In the majority of the analyses shown, the carbohydrate content has been determined by difference. By far the greatest part of the carbohydrate is undoubtedly starch. The presence of traces of dextrins and sugar is to be expected, though no report of any thorough investigation appears to have been published. Anderson and Krznarick[25] and Krznarick[26] have reported on the hemicelluloses of oat hulls; in the analysis of the whole grain these must certainly be included in the carbohydrate fraction.

Mineral matter.—Analyses of the ash of oats are quoted by Winton and Winton[2] and by the U.S. Department of Agriculture,[27] as shown in Table XIII.

Bertrand and Ghitescu[28] in an ultimate analysis of the entire oat plant report manganese (0·0005 per cent. Mn) and zinc (0·0025 per cent. Zn). Lindenbaum[29] reports the distribution of phosphorus

TABLE XIII

COMPOSITION OF ASH OF OATS

Authority	2	2	27
K_2O	16·6	16·4	15·91
Na_2O	2·6	2·2	4·38
CaO	3·8	3·7	4·09
MgO	7·0	7·1	7·18
Fe_2O_3	0·5	0·7	0·20
P_2O_5	22·6	23·0	24·34
SO_5	1·6	1·4	0·48
SiO_2	44·9	44·3	42·64
Cl	0·6	0·6	1·02

as 0·084 per cent. mineral P_2O_5, 0·573 per cent. phytic P_2O_5, 0·133 per cent. other organic P_2O_5. Greaves and Hirst[30] give—

Total	P from 0·451 per cent.	to 0·267 per cent.	Average	0·377 per cent.
Inorganic	P ,, 0·054 ,,	,, 0·021 ,,	,,	0·037 ,,

Winton and Winton[2] report from various sources the following further details of the lesser mineral constituents:

TABLE XIV

LESSER MINERALS IN OATS (AFTER WINTON AND WINTON)

Iron	34–78	Average 50	mg. per kilo	dry basis
Aluminium ..	5·2		,,	,,
Manganese ..	23		,,	,,
	35–60	Average 49	,,	,,
	8·8		,,	,,
	66–204		,,	,,
Copper	17·1		,,	,,
	8·1		,,	,,
Zinc	32·44		,,	,,
	22		,,	,,
Arsenic	0·5		,,	,,

It will be observed that all the above details of mineral matter refer to the whole oat; their applicability to oatmeal and other oat products is doubtful. Table XV gives details of the mineral analysis of oatmeal as reported by different authorities and includes several figures for the iron content which do not form part of a complete

TABLE XV

MINERAL CONTENT OF OATMEAL, MG./100 G.

Authority	Na	K	Ca	Mg	Cu	Fe	P	Cl	S
Sherman[31]	62	344	69	110	—	3·8	392	69	202
McCance and Widdowson[44] ..	33·4	368	55·3	113	0·23	4·12	380	73	155
Morrison[45]	60	370	60	110	—	4	450	70	—
Rowett Institute[46] ..	—	—	69	—	—	4·15*	392	—	—
Winton and Winton[2]	—	—	—	—	—	3·7	—	—	—
Hoffman, Schweitzer and Dalby[47] ..	—	—	—	—	—	8·0	—	—	—
Toscani and Rezikoff[48]	—	—	—	—	—	5·1	—	—	—
Fraps and Fudge[49] ..	—	—	—	—	—	6·5	—	—	—
Bridges[50]	—	—	—	—	—	3·8	—	—	—

* Of this, 3·98 mg. is available (ionizable).

analysis. It will be observed that the figures are largely of the same order, the exceptions being the low Na figure quoted by McCance and Widdowson and the high Fe of Hoffman, Schweitzer and Dalby. Davidson[32] states that manganese is present to the extent of 0·0067 per cent. to 0·0204 per cent. Mn_3O_4 in whole grain and 0·0052 per cent. Mn_3O_4 in rolled oats having a total ash of 2·13 per cent. Hutchison[51] states that Scotch oatmeal has a phosphorus content of 380 mg. per 100 g., of which 160 mg. (42 per cent.) is in the phytic form. He also quotes McCance and Widdowson's statement that 66 per cent. of the P in rolled oats is in the form of phytin.

Since the rachitogenic property of oatmeal appears to be intimately bound up with its calcium, magnesium, and phytic acid content, it seems strange that so few analyses for these constituents have been published. Harrison and Mellanby[52] state that the amount of phytic acid in oatmeal is approximately twice that required to precipitate the calcium of the cereal at neutrality.

Enzymes.—Neglecting investigations on the sprouting grain, very little work has come to light on the subject of enzymes in oats or oat products. Giesen[33] reports the presence of a protease; Wierzchowski[34] says that maltose is present in small amount, while Baker and Hulton[35] report the presence of amylase. During the examination of the samples reported in Table VI it was thought that it might prove interesting to test the various products for amylase activity by the routine methods in use in the writer's laboratory. Table XVI gives the results obtained. The maltose number gives the number of g. of maltose produced by 100 g. flour when digested under standard conditions at 30° C., and thus is largely a measure of the β-amylase activity. The method adopted is that of Blish and Stanstedt.[36] The dextrin figure is obtained by the method described by Kent-Jones and Amos[37] and gives the weight of dextrin in g. produced from 100 g. flour after digestion at 62° C. It is thus essentially a measure of the α-amylase activity.

TABLE XVI

AMYLASE ACTIVITY OF OATS AND OAT PRODUCTS

	β-Amylase maltose No.	α-Amylase dextrin. fig.
Raw oats	1·22	4·8
Kiln-dried oats	0·83	3·0
Oat groats	0·59	3·9
Pinhead oatmeal	0·63	3·2
Breakfast oatflakes	0·45	4·1
Medium oatmeal	0·52	4·0
Fine oatmeal	0·64	3·0
Oat flour	0·75	4·2
Wheat flour (for comparison)	1·5–3·0	4·0–6·0

While there are some unexplained anomalies in the table, it would appear that, first, there is some destruction of both enzymes during kiln drying and, secondly, that there is some destruction, at least of the β-amylase, during the cooking involved in the production of the flaked oats.

Vitamins.—Examination of the literature leads to the conclusion that oats in their vitamin contents are very similar to other cereal grains. Vitamin A activity is probably absent and neither vitamin D nor vitamin C occurs in the ungerminated grain, though the latter is almost certainly developed in the sprouting seed. The oil of oats should be a source of vitamin E, but on this point reliable data, even of a simple qualitative kind, seem to be lacking. According to Pyke,[38] the vitamin B_1 (aneurine) content of prepared breakfast oatmeal has been found to be :

Author	I.U. per 100 g.	Mg. aneurine per 100 g.
Cowgill	110	37
Fixsen and Roscoe* ..	140	47
Pyke	95	32

* From their vitamin tables ; the reference is actually to a paper by Baker and Wright.[54]

The figures given in Tables VI and VII were found by the author, using Pyke's method ; they are of the same order as those quoted and the range is probably due to natural variation among samples. Very much higher figures have been quoted by some previous authors (the highest was 325 I.U. per 100 g.), but more recent tests, probably with improved technique, have not confirmed their figures. I have found no records of specific biological tests. Oats have been reported to contain 0·11 mg.[55] and 0·11 mg. to 0·15 mg.[58] of riboflavin : 1·1 mg.[56] and 0·74 mg.[59] of nicotinic acid : and 1·1 mg. of pantothenic acid[54]—all per 100 g.

Antioxidants.—The presence of an antioxidant in oat flour has been noted by Peters and Musher[39] and its efficiency in retarding the rancidification of such diverse materials as lard, potato crisp, coffee beans and fatty fish has been reported on by Conn and Asnis[40] and Davies.[41] Moeller and Mack[53] have discussed the property as applied to dairy products. Shellenberger[42] suggests that malted oat flour used to increase the gassing power of wheat flour has the additional advantage of enhancing its keeping quality.

Oat products as consumed.—As with all other cereals, the manufacture of meal or flour is only an intermediate stage in the preparation of the material for human consumption. Probably the bulk of the oatmeal produced is consumed as either porridge or oatcake.

Porridge is, of course, prepared by boiling the meal with water and a little salt, and varies so much in composition owing to differences in water-content that it is difficult, if not impossible, to give any significant figures for the composition of the resultant foodstuff. A few experiments with medium oatmeal, however, indicate a loss of 5 per cent. to 10 per cent. of the vitamin B_1 on boiling for 30 minutes. This is of the order that we should expect, since the temperature is never above boiling point and the reaction of the medium is slightly acid (see Table VI). The results are similar to those obtained by Dawson and Martin[43] with bread. With oatcakes, the common practice is to use fat, preferably dripping, to the extent of 14 per cent. to 18 per cent. of the meal, and sodium bicarbonate at the rate of about 0·9 per cent. is added as a raising agent. Since the cake is baked to dryness on the hotplate, the temperature reached is probably above boiling point, and this in the alkaline medium tends to the destruction of B_1. Preliminary trials suggest a loss of about 25 per cent.

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Part V

MEAT AS FOOD

(*Papers read at a meeting on 29th April,* 1942)

CHAPTER XVII

FACTORS INFLUENCING THE COMPOSITION AND PROPERTIES OF MEAT

By John Hammond

In order to understand the causes for the variations in the chemical composition of meat it is necessary to look at meat from the point of view of the animal producing it. To this end let us first follow the age changes in the animal. The lamb, for example, when it is born, is all head, shins, and shanks, parts of low meat value ; as it grows up, the body first lengthens and then thickens so that the proportions of the head and shanks become less. That is, there are growth gradients in the animal ; the primary one starts at the head and passes backwards, while secondary ones start at the other extremities—feet and tail—and all these waves of growth meet at the loin. The least valuable extremities are therefore early developing parts and the most valuable, loin, a late developing part of the body. Similarly growth gradients exist between the different tissues of the body : bone is early maturing, then muscle, while fat is late maturing.

What these growth changes mean to the butcher and consumer is shown by the fact that an animal *shaped like* the lamb at birth will yield for every 100 lb. live weight only 53 lb. of carcase, whereas one *shaped like* that of the adult ram will yield a carcase percentage of 67 per cent. Associated with these changes in shape and carcase percentage there is a change in composition. Thus from the consumer's point of view, while there is 31 per cent. of edible meat and 17 per cent. of bone in the lamb at birth, in the adult ram there is double the proportion of edible meat, 62 per cent., and only 4 per cent. of bone. Only 2 per cent. of this edible meat is gross anatomical fat in the lamb, while in the adult ram there is 30 per cent. Thus, the general shape of the animal and the carcase percentage it yields give in themselves a good indication of the composition of the meat. The composition of the meat animal can be controlled to a considerable extent by the plane of nutrition at which it is grown. As McMeekan has shown in the pig, and Verges in the sheep, a high plane of nutrition speeds up the age changes in form, carcase percentage and composition, while a low plane of nutrition slows them down. This is caused by the fact that the early developing parts (head and shanks) and tissues (bone) have first call on the nutrients available and so the late maturing parts (loin) and tissues (fat) have to go short when the animal is on a low plane of nutrition. In fact the way in which the breeder has improved his animals for meat is to put them on to a high level of nutrition, which allows the more valuable loin to grow to its full genetic limit, and then pick out and breed from those which show the best development. Thus while the unimproved animal, such as the wild boar, grows up with little change in the proportional development of loin to head, or fat to bone, the improved breeds change greatly in these respects as they grow up.

The composition of the meat is naturally not the same in all the joints from the same carcase. For example, on the average in four fat mutton carcases the loin contained 36 per cent. of fatty tissue, 54 per cent. of muscle, 8 per cent. of bone, and 2 per cent. of tendon, etc., whereas the leg contained 22 per cent. of fatty tissue, 61 per cent. of muscle, 11 per cent. of bone, and 6 per cent. of tendon, etc. Consumer tastes vary in different districts and in different trades, but generally speaking there is an optimum amount of fat required in meat—there can be too much as well as too little. As certain parts of the carcase tend to put on fat at a quicker rate than others, one part may be over-fat, while the fat in another may be in the correct proportion. Thus, while in South American lambs the loin makes a higher price than the leg, because the loin has sufficient fat and the leg has not enough, in South American mutton the leg makes more than the loin because the leg has enough fat but the loin now has too much fat. Fat is deposited in connective tissue in different areas of the body. The internal fat such as the kidney and caul fat is of use as suet, but does not add to the value of the meat itself. Fat is also deposited between the muscles and acts as a padding to fill up the spaces between them ; in some areas of the body such as the thorax and shoulder there is much of this type of fat. The layer of subcutaneous fat is especially important, as it prevents the meat drying up both in storage and on cooking : it tends to thin out on the extremities. To improve this, breeders select for short legs in meat-producing animals ; this reduces the difference in degree of fattening between the leg and loin, as previously mentioned. Fat is also deposited in the muscle itself (marbling fat) during the later stages of fattening and this is most valuable, especially in beef, as it alters the texture of the muscle.

The colour of fat in beef is of some interest, for it is used by the butcher to judge the history of the carcase he buys. The orange colouring matter of plants is deposited as carotene in the body fat, in varying degrees in different breeds. When fat is withdrawn from the body during periods of poor feeding, the colour becomes concentrated in the fatty tissue, so that cows and old animals usually have darker coloured fat than young animals which have been quickly fattened. The firmness of the fat is especially important in pork and bacon, in which it is often too soft to suit the public taste. One of the main factors affecting it is the temperature of deposition; thus in cold-blooded animals, such as fish, the fat has a low melting point, whereas in sheep with a high body temperature the fat has a high melting point. This apparently applies also to different parts of the same animal for the internal fats, such as kidney fat, where the temperature is high, have a higher melting point than the subcutaneous fat, where the temperature is lower. The stage of fattening also affects the consistency of the fatty tissue. In the early stages of growth and fattening the fatty tissue is softer and the percentage of fat in it is lower than at the later stages. Fat formed from carbohydrates in the food also has a higher melting point than has fat laid down from the fat in the food, as most fats in feeding stuffs have a lower melting point than body fats.

Now let us consider various factors that affect the properties of muscle. The intensity of flavour of muscle is closely associated with the colour due to muscle haemoglobin. For each type of meat there is an optimum colour: thus with beef the dark-coloured flesh of bulls is too highly flavoured, while very pale flesh of young animals will be lacking in flavour. Colour scales have been produced to measure this. The amount of muscle haemoglobin present depends on various factors. Its function is to sustain prolonged action by the muscle and so the muscles of game animals—hare, grouse, deer—are darker in colour and more highly flavoured than the domesticated rabbit, fowl, and sheep. Moreover, this difference is to be found between the various muscles in one animal; thus in the leg of mutton the extensor pedis muscle, which is continually functioning to keep the leg in an upright position, is dark in colour, whereas the semi-tendinosus muscle, which is only brought into use occasionally, is pale in colour. Increased age and exercise increase the colour of muscle, while the absence of iron from the food, as in milk-fed veal, decreases it.

The texture of muscle, and so its eating qualities, depends on the grain or size of the muscle bundles within the muscle. In large animals such as cattle, these bundles, and so the grain and texture, are coarser than in small animals such as sheep. Similarly within any one animal some muscles are finer grained than others ; thus in the leg of mutton the gracilis is much finer in grain than the vastus muscle. Since the size of the muscle fibres increases with age, so does the size of the muscle bundles and coarseness of texture of the meat. The coarseness of texture of meat can therefore be affected by anything which tends to split up the muscle bundles : hanging, which causes the connective tissue binding to soften ; beating with a chopper against the grain ; and the deposition of fat (marbling fat) within the muscle. These means of improving the texture of muscle are of especial importance in beef, for it has a much coarser grain than mutton or pork.

CHAPTER XVIII

THE CHEMICAL COMPOSITION OF MAMMALIAN AND AVIAN MEAT

By E. C. Bate-Smith

For the purposes of chemical review, meat can be conveniently divided into the anatomical elements muscle and connective tissue, and the latter subdivided again into fatty and non-fatty tissue. This anatomical differentiation must, however, be reintegrated when considering meat as it is eaten, since, as Hammond has pointed out, the edible meat of a carcase consists of more or less intimate mixtures of these tissues in varying proportions. For instance, what is ordinarily considered lean meat may actually contain more fat than protein. Although, therefore, it is proposed to deal with these tissues separately, and especially with muscle, some space will be devoted to indicating the extent to which they enter into the composition of meat as a whole.

Muscle

Typical muscle freshly removed from the living body has the composition indicated in Table I. The amount of fat included in this analysis represents only the rather variable amount that is contained in the muscle cells, and does not take into account the abundant intercellular adipose tissue.

The proteins of muscle—The proteins can be separated into five main groups, myosin, globulin X, myogen, the pigment protein, and the extracellular protein, the first four groups being constituents of the muscle cell proper. The extracellular protein, consisting mainly of collagen, can be sharply differentiated from the remainder of the muscle protein by its complete insolubility in dilute mineral acid and this affords an easy method of determining the amount present in muscle. The amount of extracellular tissue is one of the most important factors determining the physical properties of lean meat. In the first place there is a broad correlation between the toughness of meat and its extracellular tissue content, and secondly the flavour, colour, vitamins, most of the salts, and most of the biological value of the proteins of meat are associated with the

TABLE I

Analysis of typical mammalian muscle

			Per cent.	Total per cent.
Water				75·0
Protein (≡ 3·05 per cent. N)				18·5
Extracellular (collagen, etc.)			2·4	
Intracellular: myosin			10·8	
myogen fraction			1·5	
globulin fraction			3·6	
myoglobin			0·2	
			18·5	
Soluble non-protein substances				3·5
	Per cent. N	Wt. per cent.		
(*a*) *Nitrogenous*	≡ 0·40			
Carnosine Anserine	≡ 0·125	0·5		
Creatine	≡ 0·13	0·1*		
Adenosinetriphosphate (A.T.P.)	≡ 0·04	—†		
Urea, ammonia	≡ 0·03	0·06		
Glutathione	≡ 0·01	0·04		
Amino-acids, purines other than A.T.P.		Traces		
Total identified	> 0·335	> 0·70	0·8	
(*b*) *Phosphorus containing compounds*—				
	Per cent. P	Wt. per cent.		
Orthophosphate	≡ 0·02	0·1		
Phosphagen	≡ 0·075	0·5		
Adenosinetriphosphate	≡ 0·05	0·3		
Hexose phosphate, etc.	≡ 0·005	0·05		
Total	0·15	0·95	1·0	
(*c*) *Other inorganic constituents*—				
Na	0·05			
K	0·42			
Ca	0·01			
Fe	< 0·01			
Mg	0·03			
Cl	0·06			
HCO_3	0·06			
	0·64		0·7	
(*d*) *Carbohydrate*—				
Glycogen + lactate		0·9	0·9	
(*e*) Traces of a large number of intermediary metabolites—say			0·2	
Fat (intracellular)				3·0

* 0·4 but only 0·1 free (see phosphagen).

† All bound (see under phosphorus—containing).

cellular constituents rather than with the extracellular, which therefore acts as a diluent of these qualities. In Tables II and III are presented some data on the variation that can be met with in the extracellular tissue content of the muscles of different meat animals, and of tough and tender cuts from the same animal.

TABLE II

EXTRACELLULAR PROTEIN IN MUSCLES OF MEAT ANIMALS

	Extracellular protein N per cent. of coagulable N
Beef, fillet—	
Bobby calves	13·3–13·7
Steers, 1–2 yr.	5·1–8·5
Heifer, 2 yr.	5·7
Steers, 3–4 yr.	6·8–9·7
Cows, 5–12 yr.	4·0–7·1
Thin flank	18·2–21·1
Sheep, rectus femoris—	A* B*
live weight, 150 lb.	8·1–7·4
130 lb.	8·8–7·8
110 lb.	10·3–11·2
90 lb.	13·4–11·6
70 lb.	15·2–9·7
Rabbit, mixed muscles	8·8–22·0
longissimus dorsi	5·0
abdominal muscle	19·0

* These animals were of the same original weight, but fed for two periods at different nutritive levels. Those in column A were underfed originally and then fed on a high nutritional plane, those in column B were fed on a high plane and then practically starved.

TABLE III

COLLAGEN AND ELASTIN (EXTRACELLULAR PROTEIN) IN VARIOUS CUTS OF BEEF (MITCHELL, HAMILTON AND HAINES[1])

Cut	Collagen and elastin N per cent. of coagulable N*
Round steak	12·2–14·5
Porterhouse steak	12·2–14·2
Sirloin steak	13·0–15·0
Ribs (9, 10, 11) eye	7·7–10·0
Chuck ribs (2, 3)	16·9–19·4
Fore shank	22·8–27·8
Navel	16·7–19·2
Tenderloin	8·1–10·8

* These values are calculated from the original, which are expressed as per cent. of total N, allowing 11·0 per cent. of non-coagulable N throughout to bring them into line with those in Table II.

The intracellular proteins—These proteins are differentiated by their solubilities in water and aqueous salt solutions. The water-soluble fraction consists of myogen and the pigment proteins. The fraction soluble in dilute salt-solution is the globulin X and that soluble only in concentrated solutions is the myosin. Only for rabbit muscle have the proportions of these fractions been recorded.[2] Myosin, which appears to be a pure protein, represents 67·5 per cent. of the total intracellular protein, the myogen group, which is complex, about 10 per cent. and the globulin X group 22·5 per cent. The pigment fraction in rabbit muscle is very small indeed. Myosin is common to all animals, birds, and fishes and if, as is very probable, the muscles of other meat animals contain an amount of myosin similar to that found in rabbit muscle, it can be calculated that in our pre-war diet this was the most eaten of all proteins, amounting to 17 g. a day, with casein running it a close second at 14 g. a day. The amino-acid constitution of myosin is, therefore, well worth considering from the point of view of its nutritive properties.[3] A fairly complete analysis has recently become available and is reproduced in Table IV.

TABLE IV

AMINO-ACID ANALYSIS OF RABBIT MYOSIN

Amino-acid	N per cent. protein N	Wt. per cent protein
Glycine	2·1	1·9
Alanine	3·5	3·7
Valine	2·2	3·0
Leucines	7·1	11·1
Proline	0·4	0·5
Phenylalanine	2·0	4·0
Threonine	0·9	1·2
Methionine*	1·9	3·4
Cystine*	0·56	0·77
Tyrosine*	1·6	3·4
Tryptophan*	0·66	0·82
Arginine	13·4	7·0
Histidine	2·8	1·7
Lysine	11·3	9·9
Glutamic acid	12·5	22·1
Aspartic acid	5·6	8·9
Ammonia	7·9	1·6
Total accounted for	76·4	85·0

* From Bailey (*Biochem. J.*, 1937, **31**, 1406).

It is only to be expected that the protein of muscle represents a complex mixture. The enzymes already recognized in muscle amount to more than twenty and each of these must be reckoned at least a single individual protein. Myosin itself appears to be identical with adenosinetriphosphatase,[4] zymohexase has recently been prepared in a pure state from the myogen fraction, of which it forms about 10 per cent.[5]; and still more recently phosphorylase amounting to 2 per cent. of the protein of the aqueous extract has been prepared in a crystalline state.[6] Judging by the description given of its preparation, phosphorylase would belong to the globulin X fraction. It is obviously useless at present to endeavour to survey the properties of these complex fractions. One can only predict that they will be found to correspond to the sum of the properties of the water-soluble and water-insoluble enzymes, respectively.

The pigment proteins—The red colour of meat is mainly due to myoglobin, a pigment protein very similar in properties to haemoglobin, the pigment protein of blood. The amount of this pigment varies within very wide limits, with the species, with the particular muscle, and with the age, activity, and feeding history of the animal. Few actual determinations on meat animals are recorded however. Watson[7] gives a value of 0·67 per cent. for the myoglobin content of a specimen of shin beef, and Robinson[8] quotes 1·084 per cent. for the average of a number of specimens of ox muscle. For the rest, it is only possible to draw fairly obvious conclusions from the appearance or depth of colour of the flesh, such as the greater concentration of pigment in the breast muscle of flying birds as compared with fowls; and the rapid increase in the colour of the flesh when calves and lambs are turned out to grass. Myoglobin is red in the presence of oxygen and purple-brown in its absence. The reduced form can oxidize to methaemoglobin, which gives to meat a rather unpleasant brown colour. The reduced form also reacts with nitrite to form nitrosohaemoglobin, the pigment present in uncooked bacon and ham. Boiling changes this to the bright pink nitrosohaemochromogen.

A second pigment, also red in colour, which becomes of significance only in the comparative absence of myoglobin, is cytochrome C. Values recorded for meat animals are[9]: pigeon (breast muscle) 0·04 per cent., pork (shoulder) 0·01 per cent., beef 0·005 per cent. of the weight of the tissue.

The non-protein constituents of muscle—These substances make up about 3·5 per cent. of the weight of the tissue. They may be broadly classified as (*a*) lactic acid and glycogen, (*b*) nitrogenous bases, and (*c*) salts. They are important because amongst them are to be found the substances responsible for the taste of meat; lactic acid and the salts contribute in some degree to this quality, but the characteristic taste substance is still unidentified.

(*a*) *Lactic acid and glycogen*—The normal range of lactic acid concentration in lean meat is 0·6 per cent. to 1·2 per cent. Practically the whole of this is formed after the death of the animal, from glycogen originally present in the living muscle, and a proper development of lactic acid is essential to the production of meat of satisfactory texture and keeping qualities. The effect of lactic acid is due to the fall in *p*H which accompanies its production. Broadly speaking, 0·5 per cent. of glycogen in breaking down to lactic acid will cause a shift of 1 *p*H in muscle. From the *p*H of living muscle, in the neighbourhood of 7·5, *p*H must fall to 6·2 or below, otherwise the meat is flabby and sticky and is liable to decompose with great rapidity. If a sufficient amount of glycogen is present, the *p*H will fall to *p*H 5·4 or a little below, but when this point is reached, however much glycogen may have originally been present, its breakdown to lactic acid can proceed no further. Muscle exceptionally rich in glycogen will, therefore, still contain a residue of this material when the process of rigor mortis is complete.* When fully in rigor, mutton, pork, the smaller meat animals, and poultry seldom contain glycogen, but small amounts are often present in beef and large amounts in horseflesh. For instance, as much as 2·4 per cent. of glycogen has been found in freshly killed horse's muscle. Half of this at the most will break down to lactic acid, so that the dead flesh would contain more than 1 per cent. of glycogen. Glycogen is, however, neither constantly present in horseflesh nor constantly absent from other meats, so that the presence of glycogen, which has been suggested as a test for horseflesh, is a very uncertain index.[10]

The lactic acid content and consequently the *p*H reached in rigor are influenced by starvation, excitement and fatigue. The values also vary from one muscle to another, as the following figures for *p*H show:

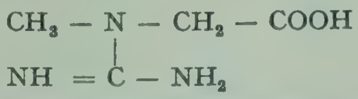
	Highest	Lowest	Average
Beef (22 carcases)—			
Fillet	5·7	5·3	5·45
Leg	5·6	5·3	5·5
Shin	6·0	5·5	5·75
Bacon pigs (32 carcases)—			
Psoas	6·4	5·4	5·7
Long. dorsi	5·7	5·3	5·5

(*b*) *Nitrogenous bases*—The proportion of the total nitrogen of muscle present in this form averages about 11 per cent. In 21 beef carcases examined the highest percentage was 13·7, the lowest 9·8. Its absolute amount represents between 0·35 and 0·45 per cent. of the weight of the muscle. This fraction has been subdivided by Furth into ammonia, purine, creatine, carnosine, amino-acid, polypeptide, and urea nitrogen, but complete analyses in this sense are only recorded for horse muscle, as follows:

Ammonia N	Purine N	Creatine N	Carnosine N	Amino-acid N	Polypeptide N	Urea N	Total extract N
0·017	0·023	0·101	0·116	0·022	0·009	0·030	0·382
0·022	0·036	0·121	0·105	0·008	0·002	0·004	0·327

From these and other incomplete analyses it is apparent that the greater part of the non-protein nitrogen is derived from three particular fractions:—the creatine, carnosine and purine fractions.

Creatine: methylguanidylacetic acid.



$$\begin{array}{l} CH_3 - N - CH_2 - COOH \\ \qquad\quad | \\ NH = C - NH_2 \end{array}$$

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* Fifteen samples of lean beef recently examined illustrate this point: 9 samples above *p*H 5·5 had on the average 0·07 per cent. of glycogen; 6 samples below *p*H 5·5 had 0·25 per cent. on the average, the highest glycogen being 0·44 per cent. and corresponding to the lowest *p*H 5·36.

In the living muscle creatine is largely combined with phosphoric acid as phosphagen, which breaks down during rigor mortis into its components. In normal animals of any given species the variation in creatine content is not large, nor is there a wide variation between different muscles of the same animal. Some values for meat animals taken from Hunter's monograph[12] are presented in Table V.

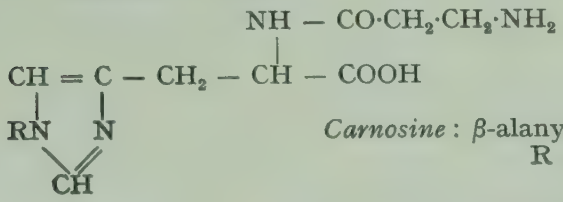
TABLE V

CREATINE CONTENT OF MUSCLE*

Species	Muscle	Extremes	Averages
Ox	Unspecified	0·312–0·532	0·366–0·467
Sheep	,,	0·406–0·419	0·413
Pig	,,	0·364–0·472	0·392–0·452
Rabbit	,,	0·355–0·571	0·425–0·528
,,	Red (mixed)	0·277–0·380	0·339
,,	White (gastrocnemius)	0·405–0·578	0·518
,,	Red (semitendinosus)	0·256–0·310	0·281
		0·258–0·306	0·277
,,	,, (soleus)	0·274–0·327	0·297
		0·343–0·371	0·354
,,	White (tibialis)	0·476–0·519	0·501
,,	,, (adductor)	0·513–0·589	0·548
,,	,, (rectus femoris)	0·523–0·543	0·533
,,	,, (adductor magnus)	0·555–0·578	0·567
Fowl	Leg	0·348–0·368	0·361
	Breast	0·408–0·481	0·445
		0·452–0·483	0·468
Duck	Unspecified	—	(0·418)
Goose	Leg, breast, and unspecified	0·348–0·522	0·366–0·470
Pigeon	Breast	0·427–0·464	0·447

* From Hunter.[12]

The Carnosine Fraction



Carnosine : β-alanylhistidine
$R = H$

Anserine : β-alanylmethylhistidine
$R = CH_3$

These two substances, which are peculiar to muscle, account for a large part of the non-protein nitrogen. Until quite recently it was thought that carnosine predominated in the muscles of mammals and anserine in the muscles of birds, but it now appears that, with the exception of the horse and ox, anserine is present in higher concentration than carnosine in all mammalian as well as all avian muscle investigated. Both substances have a strong buffering action at the neutral point, a property which is sufficiently rare in the non-protein compounds present in muscle to serve as a basis for their determination.[13] Some typical values for the concentrations of these bases in the muscles of meat animals are collected in Table VI. The values quoted under Method 1 for anserine are those of Wolff and Wilson,[14] under Method 2 those obtained by titration between *p*H 6 and 7·5.[13]

TABLE VI

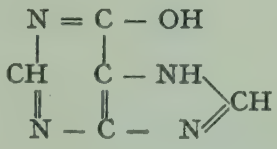
CARNOSINE AND ANSERINE CONTENT OF MUSCLE

Species	Per cent. carnosine	Per cent. anserine Method 1	Per cent. anserine Method 2
Ox	0·25	0·14	—
	0·35	—	0·1
Sheep	0·14	—	0·3
Pig	0·28	—	0·3
Rabbit	0·08	0·50	—
	0·26	—	0·5
	0·11	—	0·3
Fowl	0·05	—	0·3
	0·12	0·42	—

Determinations of carnosine alone are more numerous. These indicate that there is a very wide variation between different species, different individuals and different muscles in their content of this constituent.

A notable feature of the constitution of carnosine and anserine is the β-alanine residue, which also occurs in pantothenic acid. No certain physiological function has yet been ascribed to these compounds ; unlike so many of the meat bases, they do not appear to be esterified with phosphates in the living muscle. When injected or taken orally, carnosine has a strong depressor action on the circulation, but anserine has no action of this kind.

Purines—The purines in meat are derived by enzymic hydrolyis during the first few hours post-mortem from complex molecules present in the living tissue. Although at least four purines, viz., hypoxanthine, xanthine, adenine and guanine are described as occurring in meat, the evidence is conclusive[15] that one of these, hypoxanthine



overwhelmingly predominates. Its parent substance in muscle is adenosinetriphosphate (A.T.P.), which occurs to the extent of about 0·3 per cent. to 0·4 per cent. corresponding to 0·04 per cent. to 0·055 per cent. of nitrogen. The breakdown of A.T.P. proceeds, through the removal of phosphoric acid, to adenylic acid, which is deaminated to inosinic acid, and then hydrolysed to hypoxanthine.

$$\begin{array}{lll}
\text{Adenosine triphosphate} \rightarrow H_3PO_4 & + & \text{adenosinediphosphate} \\
\rightarrow H_3PO_4 & + & \text{adenylic acid} \\
\rightarrow NH_3 & + & \text{inosinic acid} \\
\rightarrow H_3PO_4 & + & \text{inosine} \\
\rightarrow \text{ribose} & + & \text{hypoxanthine.}
\end{array}$$

Through loss of nitrogen as ammonia the hypoxanthine N is reduced to four-fifths that of the original A.T.P., and is therefore about 0·03 per cent. to 0·045 per cent. of the muscle, which is sufficient to account for most of the purine nitrogen quoted in analytical data.

In addition to A.T.P. other nucleotides are present in muscle, for instance, as coenzyme II, which contains adenine, but the amounts of these are almost negligibly small.

The mechanism and circumstances of the breakdown of A.T.P., particularly the later stages, are imperfectly understood, and it is quite possible that adenylic acid, inosinic acid, and inosine may frequently be present in meat at least for a considerable time after death. Mathews, for instance, reports the occurrence of 0·11 per cent. of inosinic acid in the muscle of fowls.

Ammonia, urea, amino-acids, etc—The amounts of these constituents reported are small and very variable. With the exception of ammonia derived from adenylic acid it is probable that they represent materials or products of metabolism of more or less fortuitous occurrence. Altogether they represent at the most about 10 per cent. to 20 per cent. of the non-protein nitrogen.

Other bases.—A number of other substances (some of which are vitamins and are dealt with in Chapter XX) are present in minute quantities. Carnitine, sarcosine, taurine, and methyl guanidine are reckoned among the meat bases. Glutathione, a tripeptide of glutamic acid, cysteine, and glycine, is present to the extent of about 0·04 per cent.

Utilization of Nitrogenous Extractives

This is an important question in relation to the food value of meat. It can be answered satisfactorily only by an exhaustive discussion of each particular constituent of the extract. A short summary will, however, be attempted.

Ammonia, urea, and hypoxanthine are unlikely to be of any value as sources of nitrogen for bodily requirements. Two-thirds of the quantity of creatine fed appears to be retained by the body, but it does not necessarily follow that it is usefully retained.[12] There is, however, a constant drain on the body's resources of creatine which would have to be made good at the expense of protein if not supplied by meat foods, so that it can be concluded that creatine has a sparing action on protein to the extent of about two-thirds of the amount present in the food. The histidine residue in carnosine can be completely utilized by the body,[16] but it is unlikely that the nitrogen of the β-alanyl residue can be utilized. Anserine has apparently not yet been studied from this angle. It is probable that, if attacked at all in the body, it will be completely broken down and its nitrogen lost as ammonia or urea. Of the nitrogen of the carnosine-anserine fraction, only that of the histidine residue of carnosine can, therefore, be counted as a certain gain to the body. The nitrogen of amino-acids and polypeptides is all potentially available.

The total nitrogen available may, therefore, be roughly estimated as follows:

	Per cent. of non-protein N	Fraction available	Per cent. of non-protein N available
Creatine N	30–35	two-thirds	20–24
Carnosine N—			
Beef only	30–35	three-quarters	23–27
Mutton, poultry, etc.	8–12	,,	6–9
Amino-acid N ..	3–10	all	3–10
	Total (beef) ..	.. .. ..	46–60
	,, (other types)	.. .. ..	29–43

For practical purposes an allowance of half the nitrogen of the extract would be sufficiently near. Taking an average value of 11 per cent. for the non-protein nitrogen, the approximate conversion factor for total nitrogen of muscle to protein equivalent is given by—

$$\begin{aligned} &\text{Total nitrogen} \times 0{\cdot}945 \times 5{\cdot}9^{*} \\ = {}&\text{Total nitrogen} \times 5{\cdot}6. \end{aligned}$$

This factor gives a value lower by 10 per cent. than does the usual 6·25.

(*c*) *Salts.*—Referring to Table I, which gives a broad idea of the concentrations of the principal inorganic constituents of muscle, it is evident that, when rigor is complete and all phosphoric esters are broken down, the potassium and phosphate ions predominate.

Chapter XX deals with the significance of meat as a source of minerals, but it should be pointed out here that the iron content will vary with the myoglobin content, each 1 per cent. of myoglobin corresponding to 0·0034 per cent. of iron.

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* Value for conversion of muscle protein nitrogen to protein allowing for 15 per cent. of collagen, which has 18 per cent. of nitrogen and a conversion factor of 5·55.

CONNECTIVE AND ADIPOSE TISSUE

Connective tissue forms a kind of soft skeleton which supports all the other tissues and organs of the body. In meat it is most evident in the form of tendon, or gristle, but it is also distributed in a finer state of subdivision throughout both muscle and fatty tissue. The extra-cellular protein of muscle which has already been described is, in fact, finely divided connective tissue differing in no essential respect from that found in any other part of the body. The solid constituents of the different forms of connective tissue are practically identical, but the diffuse connective tissue associated with muscle and fat differs from the compact form found in tendon in one important respect, i.e., the amount of water associated with it. Manery and others[17] found that a specimen of the former had 84 per cent. of water, whilst a typical tendon had only 61·8 per cent. These authors have also shown that the mineral constituents of connective tissue are very different from those of muscle. As has already been shown, the connective tissue content of muscle can vary very widely, and an important consequence of this from the analytical point of view is that the concentration of many other constituents, including water, will also vary with the connective tissue content. Connective tissue, for instance, contains very little potassium, phosphorus, or extractives, so that the more connective tissue is present the less per cent. of these constituents will the muscle contain. It can be calculated that muscle free from connective tissue and fat would have 77 per cent. of water, whilst muscle with 20 per cent. of connective tissue, free from fat, has 80 per cent. The principal constituent of connective tissue is collagen, a fibrous protein of strikingly individual properties. Those which most concern us from the point of view of the properties of meat are the toughness and elasticity of the collagen fibre, its easy conversion to the tender, soluble gelatine by boiling and its inadequacy as a food protein. Collagen is deficient in most of the amino-acids regarded as essential for growth. It is, however, completely digested by trypsin and when, as is usual, it is accompanied by a considerable excess of protein of high biological value, it will itself be quite efficiently utilized.

A second constituent, elastin, forms only a very small proportion of diffuse connective tissue and ordinary white tendon—never more than 10 per cent. and usually not measurable. It is practically indigestible and is not sofened during cooking. Yellow elastic tendons such as those linking the vertebrae contain about 80 per cent. of elastin on the dry weight basis. Since it is usually unpleasantly evident as gristle, collagen is likely to be thought of mainly as an undesirable element in meat. There is a general relation between toughness, as measured by machines constructed for the purpose, and collagen content, but, as is clear from the last chapter, this is only one factor in determining toughness and one that can very readily be counteracted by proper cooking. Collagen does, in fact, perform a very useful function in supporting muscular and fatty tissue and giving meat a structure and firmness. This is particularly true of fatty or adipose tissue; there is a very great difference in physical properties and palatability between rendered fat and those parts of a joint of meat commonly known as "fat," although the latter may contain as much as 90 per cent. of its weight of pure chemical fat.

Adipose tissue consists of diffuse connective tissue in which the cells have become loaded with droplets of fat. Any connective tissue may become adispose, but the tendency is greatest in the membranes supporting the abdominal viscera and in the fasciæ and diffuse connective tissue of the muscles. The composition and physical properties of fat so deposited vary with the species, with the type of food fed and with the position of the tissue in the body. The effect of diet on the composition of pork fat has been studied in great detail by Ellis and co-workers[18] and on that of the hen by Cruickshank.[19] As to position in the body, the abdominal fat is harder and melts at a higher temperature than the superficial fat, and there is a distinct gradient corresponding with the gradient in temperature from the inside to the outside of the animal.[20] These physical differences are reflected in the chemical composition of the fat; the softer the fat the greater is the degree of unsaturation of the fatty acids and the higher, therefore, is its iodine value. The component fatty acids of typical specimens of the fat of meat animals have been analyzed by Hilditch and his collaborators,[21] and data are also coming to hand from this source about the detailed distribution of the fatty acids among the triglycerides in these fats, a factor of considerable importance in determining the properties of a fat, since a fat such as mutton tallow, which contains both hard fully-saturated glycerides and liquid dioleins, is oily and greasy at ordinary temperatures and yet does not completely melt at 45° C.

Some typical analyses of the glyceride components of the fat of meat animals are shown in Table VII.

For the fowl, the separation recorded is less precise; it is given as:

Fully saturated 2; mono-"oleo" (containing up to 20 per cent. of fully saturated) 28–29; di-"oleo" (containing up to 20 per cent. of mono- "oleo") 41; tri-"oleo" (containing up to 20 per cent. of di-"oleo") 28–29 per cent. (Mol.).

These data admirably reflect the different qualities of the fats of the different meat animals, ranging from the firm abdominal fat of the ox and sheep to the almost liquid fats of poultry.

TABLE VII

GLYCERIDES IN ANIMAL FATS

Species	Site	Fully saturated per cent. (Mol.)	Mono-"oleo" disaturated per cent. (Mol.)	Di-"oleo" monosaturated per cent. (Mol.)
Sow ..	.. Outer back ..	2·2	—	95·1
	Perinephric ..	11·4	30·3	58·3
Ox ..	.. Depot fat ..	17·4	49·0	33·6
Sheep	.. ,, ,, ..	26·6	30·9	42·5

Variation in Composition of Meat

The fat content of adipose tissue can vary, according to the nutritional condition of the animal, within very wide limits. The lower theoretical limit is connective tissue containing no fat and up to 90 per cent. of water. The upper limit of fat content appears to be in the neighbourhood of 95 per cent., the maximum value recorded in Atwater and Bryant's tables for beef suet. Diffuse connective tissue, wherever it is found in the body, may become adipose, and the connective tissue of muscle is no exception. Lean meat, so-called, is usually anything but lean. Not only is there a network of adipose tissue visible to the naked eyes, but the minutest ramifications of the connective tissue also contain their quota of fat. In consequence, the overall composition of every portion of meat on the carcase, as well as the composition of the carcase as a whole, will vary according to the degree of adiposity of the connective tissue, which in its turn will vary with the nutritional condition of the animal. In beef and pork this state can be evaluated with surprising accuracy by the expert from the appearance of the live animal or from simple measurements made on the carcase, and the composition of the meat can be related to, and predicted from, the recognized market grades of these animals.

Tables of the Composition of Meat

Throughout this chapter emphasis has been laid on the wide variation in composition of meat, in both major and minor constituents, and it is clear that tables containing analytical data on meat are of little value unless they include accurate, explicit, and recognizable descriptions of the class of meat and the parts of the carcase concerned, or represent the true average of a class concerning which generalized statements can usefully be made.

The tables now in general use conform in varying degree to these requirements. Those included in the U.S.D.A. circular on the proximate composition of American Food Materials deal very adequately with variation in composition in terms of recognized market grades, but these grades are, of course, different from those recognized in this country and there seem for meat foods to be no sources of references of comparable applicability open to us.

In the introductory notes to these tables, the authors point out that it is especially difficult to establish figures of general applicability to poultry, and the classes into which these commodities need to be divided are correspondingly numerous. It is also pointed out that in birds the fat is very largely abdominal and may to a varying extent be discarded, so that it is exceptionally difficult to make estimates, for dietary purposes, of the food value of poultry as a class. These tables only relate to the proximate composition of the foodstuffs and are, therefore, lacking in details such as the percentages of mineral and non-protein nitrogenous constituents and vitamin contents. Another weakness is that the values for protein are calculated by multiplying the total nitrogen contents by the factor 6·25 and are, therefore, 10 per cent. too high. Apart from these deficiencies, the tables themselves, and the instructions which accompany them as to the uses to which they may legitimately be put, appear to be an admirable model of what is needed by food chemists in this country.

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CHAPTER XIX

THE FAT, PROTEIN AND WATER CONTENTS OF MEAT

By E. H. Callow

The exceedingly complex nature of meat has been emphasized by Hammond[1] and by Bate-Smith.[2] However, it is possible to present a much simpler picture by concentrating on the three major chemical constituents, protein, fat and water, which together account for about 98 per cent. of meat.

Meat, that is, the edible portion of a carcase, is made up of muscular and fatty tissues. The fatty tissue consists of connective tissue containing widely varying amounts of fat; thus fatty tissue from beef animals may contain as little as 12 per cent. of fat or as much as 95 per cent. The connective tissue itself, when freed from fat, contains much water, and in this tissue from the kidney fat of beef animals 87 per cent. of water (on a fat free basis) has been found on the average. Muscular tissues consist mainly of muscle fibres, and of connective tissue of the same type as that found in fatty tissues, together with a variable quantity of fat. In muscular tissues from beef animals the fat has been found to vary from 1·5 per cent. to 10·7 per cent. The water-content of the fat-free psoas muscles from beef animals has been found to be 79·4 per cent. on the average. Since this muscle contains only about 3 per cent. of connective tissue[2] it can be calculated that the muscle fibres themselves contain 79·1 per cent. The water-content of connective tissue and of muscle fibres, other than that from kidney fat and from psoas muscle, has not yet been estimated, but it is probably about 87 per cent. for connective tissue and 79 per cent. for muscle fibres. During the commercial handling of meat carcases, water is always lost by evaporation, the greatest loss being at the surface. It is not surprising, therefore, to find that even under the best conditions the average water-content of connective tissue from beef fat has dropped to 76·7 per cent. and that of the fat-free muscular tissues to 78·4 per cent. Under ordinary commercial conditions these losses are usually still greater.

When we consider meat from the whole carcase in terms of fat and protein, we find that the proportion of fat can vary within very wide limits. Thus, veal contains about 6 per cent., beef may contain over 40 per cent. and pork over 60 per cent. of fat. The corresponding figures for protein are 18 per cent. for veal, 12 per cent. for beef and 8 per cent. for fat pork. The fat to protein ratio in meat may thus vary from 0·3/1 to over 7/1. Dietetically this ratio is important. Most people do not realize how much fat there is in meat; for example, even moderately fat beef contains twice as much fat as protein.

Since the major differences in the composition of meat are due to differences in the degree of fatness, it would obviously be useful if we could calculate how the percentage of water (W) and of dry fat-free residue (R) varies with varying percentages of fat (F). These relations have now been worked out for beef. For this purpose the meat from a wide variety of animals* has been used for analyses of fat, dry fat-free residue, and (by difference) water. The animals used represented five breeds (Shorthorns, Aberdeen Angus, Hereford, Welsh, and Redpoll). There were 14 steers, 1 heifer, 2 cows, a bobby calf, and a bull. Ages ranted from 1 week to 10 years, and the state of nutrition from well fed to emaciated. Using these widely varying data, the following empirical equations have been calculated:

$$W = 78{\cdot}4 - 0{\cdot}808\,F \quad (r = -\,0{\cdot}99) \qquad . \quad . \quad . \quad . \quad (1)$$

$$R = 21{\cdot}6 - 0{\cdot}192\,F \quad (r = -\,0{\cdot}98) \qquad . \quad . \quad . \quad . \quad (2)$$

The figure of 78·4 in equation 1 represents the percentage of water in beef, and that of 21·6 in equation 2 the percentage of dry residues on a fat-free basis. The very high values for the correlation coefficient (r) indicate how little the values for individual animals vary from those defined by equations 1 and 2.

American data[3] for beef have also been utilized to calculate corresponding equations. In this case the values for F and W had been determined by chemical analysis, and R has, therefore, been calculated by difference.

$$W = 77{\cdot}4 - 0{\cdot}786\,F \quad (r = -\,0{\cdot}99) \qquad . \quad . \quad . \quad . \quad (3)$$

$$R = 22{\cdot}6 - 0{\cdot}214\,F \quad (r = -\,0{\cdot}97) \qquad . \quad . \quad . \quad . \quad (4)$$

The value for water (W) on a fat-free basis is lower, showing a greater loss of water from the American beef samples. The two sets of data, however, are very similar, and this similarity is equally clear in the equations relating the fat content of beef to its calorific value per 100 g. (C). For these equations it has been assumed that 90 per cent. of R can be utilized in the body as protein.

$$\text{Present data} \qquad C = 78 + 8{\cdot}30\,F \quad (r = +\,0{\cdot}99) \quad . \quad . \quad (5)$$

$$\text{American data} \qquad C = 81 + 8{\cdot}23\,F \quad (r = +\,0{\cdot}99) \quad . \quad . \quad (6)$$

---

* The dissection of the carcases from these animals was carried out in collaboration with Dr. John Hammond and the results are reported elsewhere.

Even without correction, the two equations give practically the same results; after correcting F for the smaller amount of water in the American samples of beef, the results are identical.

A relation in which the variability of water in meat would have little or no effect is that between the percentage of fat in the edible meat (F) and the percentage of fat in the corresponding dried meat (F/R + F). The curve showing this relation is given in Fig. 1, and it will be seen that data for English and American beef fit this curve equally well. Moreover, figures for pork, mutton, and lamb, both from American[4] and our own data, also fit this curve reasonably well. There is some evidence, too, that the data from joints of meat, as well as from the carcases as a whole, will also fit the same curve. This curve may thus be considered as the simplest way of describing the variation in the composition of meat as the degree of fatness increases. This gives us a base-line which appears to be largely independent of effects due to age, sex, breed, species, state of nutrition and stage of subdivision of the meat into joints. It remains to note in what ways this base-line can be employed.

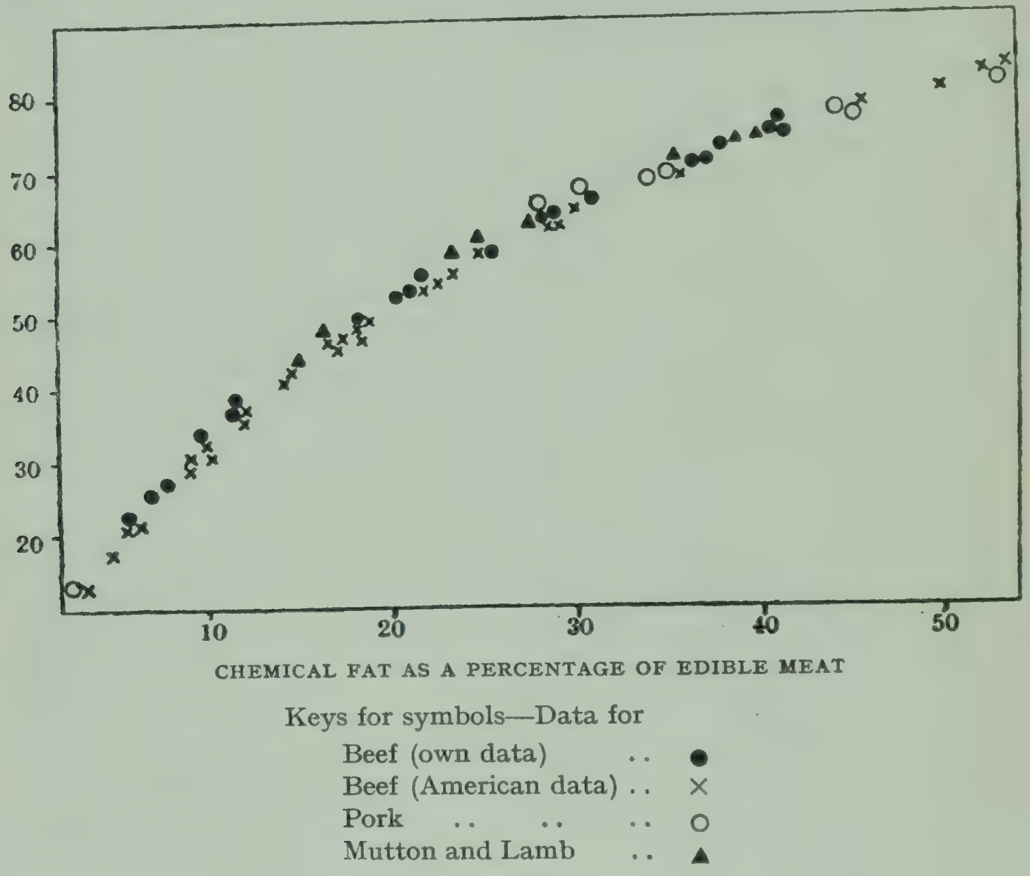

Fig. 1

(1) It can be related to dissection data giving the percentage of

fatty and muscular tissues present in carcase or joint. When once this relation has been clearly established, dissection alone will be necessary for future investigations.

(2) It can be related to the percentage of bone from a carcase. As fatness increases, the percentage of bone decreases, and the same curve appears to express the data for steers, heifers, cows and calves, but not for bulls.

(3) It can be related to the classification of fatness employed by the practical man. For steers and heifers it has been found that the percentage of fat in beef increases in a regular way with the dressing-out percentage (the weight of the cold carcase expressed as a percentage of the live weight). It will, however, be necessary to consider cows, bulls, and calves separately.

The fatness of pigs is measured practically by the thickness of back fat in relation to the carcase weight. An equation (No. 7) relating this thickness to carcase weight (W) has now been calculated, and a beginning made in relating this to the percentage of fat in pork. Where T is the thickness in millimetres of the thinnest part of the back-fat (near the last rib) and W is the weight of the cold carcase in pounds:

$$T = 1{\cdot}4 + 0{\cdot}149\,W \qquad (7)$$

Mutton and lamb are more difficult to fit, because the practical classification is merely into grades of fatness. It should be possible to describe the average fatness of mutton or lamb obtained from each grade with great accuracy and even, at a later stage, to evaluate the probable variation of individuals from this average value.

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CHAPTER XX

THE MINERAL AND VITAMIN CONTENT OF MEAT

By A. L. BACHARACH

Very little information has been supplied by British workers on the mineral composition, and still less on the vitamin contents, of meat and other edible animal products. The classical tables of McCance and Widdowson[1] provide at least a general view of the position played by foods, including meat and offals, as sources of sodium, potassium, calcium, magnesium, iron, copper, phosphorus, sulphur and chlorine, but give no data for manganese, cobalt or zinc—to mention only three of the trace elements so far incriminated in animal nutrition.

Even such a general view is absent if we wish to survey the vitamin contents of animal foods consumed in Great Britain. We are compelled, therefore, to turn for assistance to the work of American analysts and biochemistry. In their monograph on *The Vitamin Content of Meat*[2] Waisman and Elvehjem published in detail the results, many of them not previously reported, of some of their work carried out at the University of Wisconsin with the object of establishing the distribution of water-soluble vitamins in meat, both raw and cooked or processed in different ways. Besides recording their own work, the authors also surveyed the literature of the subject. In their critical evaluation of the figures reported by others and comparison of these figures with their own, they made the first comprehensive study of this field. They did more than this, for they also collected available information about those vitamins in which they themselves had not been directly interested, as well as on the mineral content of meat and the broader nutritional aspects of its chemical composition.

In addition to the monograph of Elvehjem and his colleagues, there has appeared a useful independent publication from North Carolina, where Dann and Handler[3] have used an improved chemical method for determining the nicotinic acid content of raw and cooked meat. Their values are rather lower than those previously got by chemical analysis or bio-assay on dogs, but show good agreement with the micro-biological assays carried out by the Wisconsin group and by others. References to certain other papers on the subject are made elsewhere in this chapter, which does not, however, claim to do more than summarize and "round off" the figures furnished by these and other original investigators. It is fully appreciated that what the figures thereby gain in convenience they may well lose in accuracy. There are pitfalls lying in wait for those who unwarily make use of "average" figures taken from the "centre" of a range whose relation to the true distribution of values in nature is entirely unknown ; the information at present available in this, as in almost every branch of nutrient analysis, does not justify giving anything more than the range of properly determined values reported in the literature. Of the probability that any sample chosen at random would fall within that range, and whereabout within it, we know next to nothing.

With these qualifications in mind, it is permissible to consider the figures at our disposal ; it will be convenient to take stock of the mineral elements first, and then of the water-soluble and fat-soluble vitamins separately.

On the whole, meat products are poor sources of metals, but meat and offals contain from 0·1 per cent. to 0·3 per cent. of phosphorus (cf. Bate-Smith[4]) in a variety of chemical combinations. Meat can thus make a valuable contribution to daily phosphorus requirements which may be taken (Bacharach and Drummond[5]) as 1·0 g. to 1·5 g. Of calcium, on the other hand, muscle tissue is a poor source, containing only from 5 mg. to 20 mg. per 100 g., and the same is true of liver, kidney and other edible organs. Daily requirements are between 750 mg. and 1250 mg. (cf. Bacharach and Drummond ; also the Food and Nutrition Board of the U.S. National Research Council[6]), and little dependence should be placed on meat foods as sources of dietary lime. Meat is also a poor source of magnesium, containing only about 20 mg. per 100 g. ; daily requirements have been put at something approaching 0·5 g. Bread contains from 40 mg. to 100 mg. per 100 g., according to the milling, so that it is at least twice as good a source as meat, and often much more than this.

The old-fashioned view that meat was the best "blood-forming" food, and this in virtue of its iron content, was followed by an almost complete reversal, due largely to the work of Starkenstein and others, who found that ingested inorganic iron is much more available for haemoglobin formation than is organic iron. Further investigations, however, have all tended to show that the facts cannot be summarized in any simple way.

The iron content of muscle varies from 2½ mg. to 4 mg. per 100 g., while the organs, such as liver, kidney and spleen, contain about twice as much, ranging from 5½ mg. to 8 mg. per 100 g. The difference between the food iron that will react with α-α'-dipyridyl and the iron that will not corresponds only in the most general way with the difference between metabolically "available" and "unavailable" iron. All that can safely be said at the present time is that the iron of meat seems to be reasonably well utilized, but certainly no better than iron of vegetable (e.g., cereal) origin, and possibly less so. The iron of the internal organs may have a rather higher availability than that of muscle. There is, moreover, some evidence that whole organs are more effective sources of iron than their ash.

The figures for copper in meat show some inconsistency; the matter is of more than academic interest because of the known relationship between dietary copper and haemoglobin formation. From their survey of the literature Waisman and Elvehjem[2] give figures varying from about 1·5 mg. to 5 mg. per 100 g. of, apparently, dried muscle; these figures, it would seem, are based on the work of Ivanov, to whose papers they make reference. Yet the figures obtained in their own laboratory, published by Lindow *et al.*, and also referred to in the monograph, range from one-twelfth to one-third of these values. In this they agree with McCance and Widdowson,[1] who publish a few data ranging round 0·15 mg. to 0·25 mg. per 100 g. of fresh meat. These authors find just under 6 mg. per 100 g. of fresh liver; the range given by Lindow *et al.* for livers of special species are from 0·7 mg. to 4·4 mg. per 100 g. of fresh organ. It seems likely, in any event, that an animal food supplying adequate amounts of iron will also supply adequate amounts of copper, since the requirements for copper are generally held to be not more than one-tenth of those for iron, nor do foods appear to contain any "unavailable" copper.

Muscle has been found to contain from 0·07 mg. to 0·16 mg. of manganese per 100 g., while liver may be 10 times as rich, and other tissues about twice as rich. Figures for cobalt are almost non-existent. Muscle contains from 1·5 mg. to 5 mg. of zinc and from 0·4 to 0·5 mg. of aluminium per 100 g.: liver values of 8 mg. to 12·5 mg. per 100 g. for zinc and 1·7 mg. for aluminium are reported.

A variety of methods have been used in estimating the water-soluble vitamins of the "B_2 complex." Micro-biological technique has come very much to the fore in the last five years and is still almost the only practical procedure available for systematic study of pantothenic acid and biotin contents, although both can also be estimated by biological assays on rats or chickens, for which they are essential nutrients. Nicotinic acid has been determined by various modifications of the cyanogen bromide method, especially of the procedure elaborated by Melnick and Field,[7] and also by both bio-assays on dogs and the micro-biological use of *Lactobacillus arabinosus*. Riboflavin has been most effectively estimated by a micro-biological technique, using *Lactobacillus helveticus* (*casei* ϵ), but it can be assayed fluorimetrically or by the rat-growth procedure. Tests on chicks have also been made the basis for vitamin B_6 estimation, and there is a chemical method of determination, though some recent work throws considerable doubts on its specificity, that is, on its ability to measure the vitamin, the whole of the vitamin and nothing but the vitamin. The methods of determining ascorbic acid and aneurine (thiamin) are no different in principle from those available for their measurement in other foodstuffs and in medicinal products. The pyridoxine assays of the Wisconsin workers were carried out by the rat-growth method.

On the general question as to the validity of each and all of these diverse methods, I would take refuge in a quotation from the monograph of Waisman and Elvehjem,[2] who write "The entire subject is still in a dynamic stage and much more work needs to be done before definitely reliable figures can be presented. We hope that the background of its presentation will be kept in mind when it is used." So modest and balanced an outlook establishes confidence in the authors' own figures, and justifies the use of those figures as the main contribution to the information summarized in Tables I, II and III of this chapter. It may be added that their monograph also contains short references to the less well-characterized constituents of the "vitamin B_2 complex," including choline, inositol, *p*-aminobenzoic acid and biotin.

Certain facts that emerge from consideration of the tables may be briefly noted. Liver is one of the best sources of vitamin A ; kidney is also a reasonably good source. Meat is of little importance as a source of ascorbic acid, although liver contains 10 mg. to 50 mg. per 100 g. ; kidneys approach liver in this respect, but muscle contains from none to a quarter the content of liver. Adrenal glands are an exceptionally rich source, containing up to 140 mg. per 100 g., but they are small organs and are seldom intentionally eaten.

Muscle is superior to glandular tissue as a source of aneurine (thiamin : B_1); liver and heart are superior to kidney. Miller, Pence, Dutcher, Ziegler and McCarty[8] have confirmed and extended Pyke's[9] finding that the concentration of vitamin B_1 in pig muscles is not only much higher than in those of other animals (and also than in pig's liver), but is at least in part conditioned by the amount in the animal's feed. The range is consequently large, even for a natural product. All the same, in pre-war diets bacon and ham must have made an appreciable contribution to the average daily intake of aneurine in this country.

TABLE I

FAT-SOLUBLE VITAMINS IN MEAT AND OFFALS

	Vitamin A (I.U. per 100 g.)	Vitamin D* (I.U. per 100 g.)	Vitamin E (mg. per 100 g.)	Vitamin K
Meat	50	13	0·6	Poor
Liver—				
Ox	1250–16,300	9–47	1·0	—
Calf	7000–34,000	0–15	—	—
Sheep	10,000–265,000	—	—	—
Lamb	5000–15,000	20	—	—
Pig	8000–17,000	45	—	—
Hog	11,500	—	—	Very rich
Horse	—	—	1·3	—
Chicken	650	60	—	—
Turkey	160–250	—	—	—
Kidney—				
Ox	1,000	—	—	Fair
Calf	1,000	—	—	—
Lamb	835	—	—	—
Horse	—	—	0·6	—
Heart—				
Horse	—	—	0·5	—

* Ox-, calf- and pig-liver fats have been reported to contain under 10 I.U. per 100 g.

Taking an average figure for bacon as 500 I.U. per 100 g., allowing 25 per cent. loss for cooking, and assuming 2 oz. to be consumed at a time, a breakfast portion of "bacon and eggs" would contribute some 200 I.U., or about 0·65 mg. of aneurine to the daily requirement of, say, 2 mg.[5,6] The same amount would be forthcoming from about 8 oz. of wholemeal bread, 11 oz. of National bread (85 per cent. extraction) or 35 oz. of white (72 per cent. extraction) bread.[10] These are from somewhat under to very much over the amounts of bread that are eaten daily on the average. The matter can be stated in another way. Figures recently published[26] for the aneurine content of different flours show that there are on the average 160, 175 and 195 I.U. in 200 g. of 80 per cent., 82½ per cent. and 85 per cent. flour respectively. This therefore represents the amount of vitamin B_1 consumed in the average daily intake of bread at the different levels of flour extraction. A "cut" in the weekly bacon ration of 1 oz., involving a weekly aneurine loss of 140 I.U., can therefore be largely made good—to from 75 per cent. to 100 per cent.—by a 2½ per cent. increase in the extraction of flour at these levels, or by about a 10

TABLE II

WATER-SOLUBLE VITAMINS PER 100 G. FRESH MEAT

	Ascorbic acid, mg.	Aneurine, I.U.*	Riboflavin, μg.	Nicotinic acid, mg.	Pyridoxine,† mg.	Pantothenic acid, mg.	Biotin,‡ μg.
Ox—							
Beef	0	27–100	40–350	3–10	0·2–0·45	0·2–1·3	3–6
Veal	—	40–130	70–370	5–16	0·3–0·45	0·15–1·8	4–8
Lamb & mutton	—	90–140	70–360	4–10	0·2–0·35	0·45–1·3	2–6
Pig—							
Ham . .	—	200–800	130–340	3–15	0·25–0·6	0·25–1·9	4·5–8·5
Pork . .	—	300–870	90–350	3–14	0·35–0·7	0·3–2·1	
Horse	—	—	100–135	5	—	—	—
Rabbit	4	—	40–75	6–13	—	—	—
Chicken—							
Dark meat . .	4	20–30	250–740	3–8	0·2	0·4–2·0	10
Light meat . .		7–17	25–130	9–18	—	0·5–0·7	11

— indicates that no figures have been ascertainable. * To convert I.U. of vitamin B_1 to μg. of aneurine, multiple by 3.

† Vitamin B_6, adermin. ‡ Vitamin H.

TABLE III

WATER-SOLUBLE VITAMINS PER 100 G. FRESH OFFALS

	Ascorbic acid, mg.	Aneurine, I.U.*	Riboflavin, mg.	Nicotinic acid, mg.	Pyridoxine,† mg.	Pantothenic acid, mg.	Biotin‡ μg.
Liver—							
Beef	31–38	120–130	0·9–3·0	8–28	0·4–1·01	4·5–9	90–130
Veal	32–33	140	1·5–3·6	12–23	0·3–0·45	4·5–7·5	75
Lamb & sheep	38–46	90–140	1·7–5·0	13–46	0·35	7	130
Pork ..	12–38	110–190	1·8–4·4	10–30	0·3–0·6	—	80–95
Chicken ..	18–28	—	—	11–18	—	—	—
Rabbit ..	10–40	—	0·6–1·8	8–22	—	—	—
Kidney—							
Beef	—	70–100	0·8–2·3	5–18	0·36–0·45	3–5	90
Veal	—	—		8–10	—	—	—
Lamb ..	—	—	2·7	9–10	—	—	—
Pork ..	—	180	1·9–2·0	9–16	0·4–0·7	3–4	125–135
Chicken ..	15	—	—	—	—	—	—
Rabbit ..	7–25	—	1·3–1·5	14	—	—	—
Heart—							
Beef & veal ..	0	130–210	0·4–1·0	3–11	0·25	1–2·5	7–15
Pork ..	4	180–230	0·1	8	0·35	2·5	18
Chicken ..	8	—	1·7–2·0	—	—	—	—
Tongue—							
Beef	—	90	1–0·3	6	0·1	0·2	3

— indicates that no figures have been ascertainable. * To convert I.U. of vitamin B_1 to μg. of aneurine, multiply by 3.

† Vitamin B_6, adermin. ‡ Vitamin H.

per cent. to 7 per cent. increased consumption of these breads. These figures serve to illustrate the importance of pig's meat in general, and bacon in particular, as contributors to the ordinary man's aneurine requirements.

The riboflavin content of pork and ham is, in contrast with that of aneurine, similar to that of other meats, according to Miller *et al.*,[8] and the concentration in the liver is, as usual, much higher than in the muscles.

Interesting, and puzzling, findings have been recorded by investigators who have studied the relative amounts of vitamins in light and dark meat, especially of poultry. Dann and Handler[3] reported that chicken breast muscle was found by them to be not only much richer in nicotinic acid than was any other meat, thus putting it into the same class as offals, but was 2 to 3 times as rich as the leg meat ; it had, however, only been found by Waisman and Elvehjem[2] to contain some 25 per cent. more. On the other hand, the latter workers found that the amount of aneurine in the dark meat of the chicken was from 2 to 3 times as much as in the light. Since the darker muscles owe their colour to a higher haemoglobin content and exhibit a more vigorous metabolism than the lighter, one can only speculate that the cellular oxidative processes in the two types follow different paths. There is some indication that the riboflavin distribution follows that of the aneurine rather than that of the nicotinic acid.

Daily requirements for riboflavin—2·5 mg[5,6]—could be met by 1 lb. or 2 lbs. of most meats : about a quarter to a half that quantity would satisfy the daily need for nicotinic acid—16 mg.[5,6]

Few figures for the vitamin B_6 (pyridoxin, adermine) contents of meat and offals have been published since the appearance of the monograph by Waisman and Elvehjem[2]: these authors made the observation that "muscle tissue must be considered a better source of vitamin B_6 than liver"—the reverse of what occurs with other water-soluble vitamins. About 2 mg. of pyridoxine would be supplied by 1 lb. of meat ; consideration of the various figures available suggests that liver and kidney are about the equal of muscle in their content of this vitamin and hardly bears out the contention of the Wisconsin workers. Practically knothing is known about human requirements for pyridoxine and even less about the need, if any, for pantothenic acid.

Figures for the biotin content of meat have been published by the indefatigable Wisconsin team[16] and are included in Table II.

Finally, it may be useful to summarize what is known about the effect of cooking on the vitamin content of meat which, after all, is hardly ever eaten uncooked or unprocessed by Western man.

Very little information is available about losses of fat-soluble vitamins: probably all resist ordinary cooking processes fairly well, especially vitamin D, although most animal (mammalian) tissues are unimportant sources of this factor.

A number of investigations have been made into the effects of cooking—broiling, braising, stewing, frying, baking or roasting—on the stability of the water-soluble vitamins in meat. Most of this work comes from the Wisconsin laboratories and presents a self-consistent picture. Thus, Schweigert *et al.*[11] found losses of aneurine from 8 per cent. to 30 per cent., of nicotinic acid only 4 per cent. and of riboflavin about 15 per cent.; McIntyre *et al.*[12] reported 30 per cent. loss of aneurine and not more than 10 per cent. loss of nicotinic acid. An appreciable amount of aneurine may be found in the dripping, but this, like the total over-all loss, varies with the method of cooking. All these studies were made on different cuts of pork and ham. On the whole, their results confirm those given by Waisman and Elvehjem,[2] which showed that frying is less destructive than broiling, baking and roasting, stewing having an intermediate effect on aneurine, with little, if any, destruction of riboflavin; the other procedures probably involved some loss of riboflavin, and all methods seem to destroy some ascorbic acid, of which, in any event, meat is a poor supplier. Among offals, only liver contributes significantly to our vitamin C requirements; the "easy cooking" of goat's liver was found by Rudra (quoted by Waisman and Elvehjem[2]) to destroy about one-third of the aneurine. Published figures on this point are, however, inadequate, in view of its practical importance, at any rate in peace time. The work of Greenwood *et al.*[13] showed that the aneurine (and co-carboxylase) of lean pork underwent from 16 per cent. to 20 per cent. loss on heating for 1 hour at 98° C. and that the rate of loss was not seriously affected by the presence of the salts commonly used for the curing of meats.

Dann and Handler[3] found varying and sometimes considerable losses of nicotinic acid during cooking; this ranged from 8 per cent. when ham was fried, to 67 per cent. when heart (lamb) was baked. On the other hand, the two papers from the Wisconsin workers[14,15] gave more reassuring results, from 62 per cent. retention during braising to 85 per cent. during roasting, whereas the retention claimed by the first two authors was only from one-half to two-thirds. This discrepancy has not so far been explained. In general, the values of Daim and Handler are on a somewhat lower level than those of Elvehjem and his associates, whether for raw or cooked meat and offals.

In conclusion, it is urged that the considerable advances made in knowledge of the subject here discussed—advances for most of which we are indebted to the Wisconsin investigators—should not blind us to the large gaps in our information. Not only are many more data required about the vitamin contents of foods in general, and meat in particular, as consumed rather than as gathered or slaughtered or purchased, but we have hardly begun to study the causes of variation from breed to breed (or variety to variety), within the breed itself or even within the carcase of a single animal. The whole field relating the condition of cropping or feeding to the nutrient analysis of crop or carcase remains almost completely unexplored. To tackle these problems adequately needs unified, co-ordinated and planned attack.

Note at time of revision.—Besides the publications of which metntion is made in the text of this chapter and in the concluding list of references, a number of other papers have been consulted, including those by Cover *et al.*,[17] Henderson *et al.*,[18] Cheldelin and Williams,[19] Waisman *et al.*,[20] Siegel *et al.*,[21] Stokes *et al.*,[22] Atkin *et al.*[23] While the above chapter was in the press, two further papers[24,25] have given additional figures, for the pyridoxin and riboflavin contents of certain meats and offals. Where these figures extend the ranges already recorded, they have been incorporated in Tables II and III above. One of these papers[24] also records some choline contents, as follows:

		Choline (mg. per 100 g.)
Ox—		
Beef		65–70
Veal		95–108
Lamb		75–92
Pig—		
Ham		101–129
Liver	(Beef)	450–570
Kidney		240–284
Heart		170
Tongue		108

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CHAPTER XXI

THE EFFECT OF COOKING AND PROCESSING ON MEAT

By L. C. Baker

When lean meat is cooked three fairly obvious changes occur: (1) The meat changes colour; (2) the texture of the meat becomes firmer; (3) the meat shrinks in size and loses weight.

It is this last effect of heat that has the greatest influence on the change in the composition of lean meat which occurs on cooking and to which most attention is devoted in this paper.

In their special report to the Medical Research Council on *The Chemistry of Flesh Foods and their Losses on Cooking*, McCance and Shipp drew attention to the fact that the losses suffered by lean meat on cooking are due very largely to an active shrinkage of the tissue on heating and a consequent loss of liquor which is forced out. The authors pointed out that this phenomenon had been rather overlooked, although it was clearly recognized by earlier workers.

1. Physiological Investigations of the Contraction of Small Muscles on Heating

This work was concerned largely with the contraction of muscle and the precipitation of the protein in the muscle on heating and the possible connection between the two. While much of the work is relevant to the cooking of meat, care must be taken to apply directly only those results obtained with voluntary mammalian muscle which had passed into rigor. Vincent and Lewis[1] found that the thigh muscles of a young rabbit which had passed into rigor, when immersed in normal saline whose temperature was slowly raised, showed a marked contraction at 63° C. On the other hand, fresh living mammalian muscle showed a sudden contraction at 45° C. to 49° C. in addition to that at 63° C. These authors also gave tracings which illustrate that other tissues, such as tendon and skin, show a marked contraction at 63° C. and they considered that the contraction of muscle at 63° C. is due to some change in connective tissue elements. The contraction of connective tissue on heating is well illustrated by the marked warping which occurs when a steak to which a strip of connective tissue is attached is grilled. However, this theory was discredited by Meigs, who worked with frog's muscles. In addition, Meigs[2] studied the changes in weight which occurred when muscle was heated. He found that living frog's muscle, when heated in 0·7 per cent. NaCl solution, showed two contractions, the first between 40° C. and 50° C. and the second about 53° C.; only the second contraction was accompanied by a loss of weight—20 per cent. for the sartorius muscle and 30 per cent. for smooth muscle from the stomach after 2 minutes at 65° C. Contraction was measured by means of a pointer attached to one end of the muscle by thin wire, the other end of the muscle being fixed. When, however, contraction along the length of a muscle is compensated by a thickening of the muscle no squeezing out of liquor and consequent loss of weight occur. When contraction is accompanied by loss of weight it is called shrinkage. That the muscle lost weight while immersed in water indicates that the tissue reacted to the heat by contracting in all directions, that is, that an active shrinkage occurred. Incidentally, it may be mentioned that in a later paper Meigs came to the conclusion, as a result of further experiments, that the shrinkage of frog's muscle was independent of the coagulation of the protein, although the facts did not preclude the possibility that the two processes were fundamentally connected.

Histologists know that tissues shrink when heated much above 50° C. in the paraffin oven. This shrinkage takes place in all directions, but chiefly longitudinally in such tissues as nerve and sendon, and is accompanied by passage of liquid paraffin out of the tissues. The second contraction of living muscle on heating retembles this shrinkage in the temperature at which it appears, in the fact that it occurs in tissue saturated with fluid and in that it is accompanied by passage of fluid out of the tissue.

2. Experimental Study of the Cooking of Meat on a Laboratory Scale

McCance and Shipp[3] have made a systematic study of the changes which occur when meat is cooked, using best chilled Argentine beef for the bulk of their work. They point out that when lean meat is thoroughly cooked in water it loses 40 per cent. to 50 per cent. of its weight, a loss which must be due to an active shrinkage, since the flesh is immersed in water.

By cooking pieces of meat supported on a wire grid in a steamer, McCance and Shipp were able to study shrink without the complications of (*a*) loss of water due to evaporation (such as occurs in roasting) and (*b*) loss of soluble components by leaching (as in cooking in water). The expressed liquid dropped through the grid and the meat never became water-logged; the saturated atmosphere prevented loss of weight by evaporation of water. Immediately it was removed from the steamer the meat began to lose weight by evaporation of water.

(*a*) *The Effects of Shrink Demonstrated by Cooking in Steam*

When lean meat was cooked in steam at 100° C., the percentage loss of water reached a steady value of a little over 50 per cent. (The amount of any component lost is expressed as a percentage of the amount of that component present in the raw meat.) This state was reached in about 1 to 1½ hours for pieces weighing roughly 2 oz. to 14 oz., but larger pieces, weighing 3¼ lb., required about 4½ hours to reach this state, presumably due to the time taken for the heat to penetrate to the centre of pieces of this size. The percentage loss of water was closely paralleled by the percentage losses of the "salts" ("salts" imply readily soluble salts), as shown in Table I.

TABLE I

400 G. PIECES OF BEEF

Time of cooking Hours	Percentage losses of				
	K	P	Cl	Average of K, P, Cl	Water
½	34·9	34·2	31·5	33·7	33·8
1	50·5	50·5	45·7	49·0	49·7
2	56·7	55·5	48·0	53·8	53·5
3	64·0	52·0	49·0	56·0	55·0
6	69·2	66·2	61·0	65·5	59·0

The steady value for the percentage loss of weight varied with the temperature of steaming, reaching values of 40 per cent. at 80° C., 43 per cent. at 100° C. and 53 per cent. at 120° C.; the rate of loss of weight was also more rapid at the higher temperatures.

To summarize these results it may be said that, if cooking is continued long enough, the percentage losses of weight, water, and "salts" become constant and are the result of the squeezing out of a saline liquor by the shrinkage of the tissue.

(*b*) *The Effects of Cooking in Water*

When pieces of lean meat about ½ in. thick and weighing roughly 2 oz., were cooked in water at 95° C. to 100° C., the losses of weight, water and "salts" were very rapid during the first ½ hour. In this time, the percentage losses of weight and water reached 42 per cent. and 54 per cent. respectively, at which values they remained steady for a further 5½ hours. Shrink, therefore, was complete in ½ hour, in which time 62 per cent. of the "salts" were lost to the water; during the following 5½ hours a further 38 per cent. of "salts" were lost more slowly as the result of leaching. The results of cooking in water, however, were influenced by the size of the pieces of meat. With larger pieces weighing about 3¼ lb. the effect of leaching became apparent at once; the percentage loss of "salts" was always greater than that of water, presumably due to the longer time taken for the heat to penetrate to the centre of pieces of meat of this size and to complete shrink. However, after 3½ hours shrink was complete, the percentage losses of water and "salts" were about 50 per cent. and 56 per cent. respectively, and no further loss of "salts" occurred. A possible explanation of the result is that "salts" diffuse through coagulated protein only with difficulty.

When the cooking of 2 oz. pieces of meat was begun in cold water, the temperature of the water being raised to the boiling point in 1 hour, no loss of weight occurred until the temperature of the water reached 60° C., although the loss of "salts" to the water by leaching began at once. Eventually the percentage losses of weight and water reached the same values as when hot water was used from the beginning.

(c) *The Effect of Roasting Meat*

Very different results were obtained when meat was roasted. The percentage losses of weight and water did not reach maxima at about 40 per cent. and 50 per cent. respectively, but continued indefinitely, clearly due to the loss of water by evaporation. The percentage loss of "salts" was very much less than in steaming or boiling. Only when liquor is lost as drippings, due to the effect of shrink, will "salts" be lost; when water is lost by evaporation the salts remain behind.

3. Experimental Study of the Cooking of Meat on a Practical Scale

In applying the results of McCance and Shipp to the practical cooking of meat it must be remembered that many of the experiments were carried on for longer than was necessary to prepare the meat for eating—the experiments were pursued to their logical conclusions. Further, the roasting of pieces of meat weighing 50 g. is of academic rather than practical interest.* Public opinion decides when a piece of meat is adequately and properly cooked for eating—that is, when it is "done." The temperature reached at the centre of a piece of meat when it is "done" is therefore a matter of some interest—by centre is meant that part to which heat takes longest to penetrate. As an example of cooking in water the cooking of boned hams in presses may be cited—these are found to be adequately "done" when the temperature at the centre reaches 150° F. (65° C.). A survey of the very considerable American literature (Sprague and Grindley,[4] Latzke,[5] Cline, Trowbridge, Foster and Fry[6]) on the roasting of beef shows that beef is considered "rarely done" when the temperature at the centre reaches 53° C. to 64° C., "medium done" at 65° C. to 70° C. and "well done" at 70° C. to 80° C. I have recorded similar temperatures, 60° C. to 70° C., at the centres of medium-done chops and steaks. It may be concluded that for meat to be done it must reach a temperature of about 60° C.—although this certainly does not mean that such a temperature is not exceeded. It would appear therefore that "doneness" is connected with the coagulation of protein which, it was stated earlier, occurs at about 60° C. to 63° C. and which presumably causes the firming of the meat. Only when beef is roasted to the "rare" stage, or when hams are not quite cooked, is the texture of the meat at the centre found to be flaccid or not firm.

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* Note. We are looking forward to the days when this statement will again be true! (Eds.).

It is, therefore, obvious that in cooking meat the effects of shrink must operate to a greater or less extent, depending on the stage to which the meat is cooked and on the cooking conditions employed. The time taken for heat to penetrate to the centre of a roast is considerable and a temperature gradient exists, falling from the outside to the centre. The degree of shrink will, therefore, not be uniform throughout the joint.

The effects of the conditions of roasting are shown in Table II, taken from a paper by Cline, Trowbridge, Foster and Fry[6], who roasted prime ribs of beef to an internal temperature of 57° C. (underdone or "rare").

TABLE II

Oven temperature	110° C.	163° C.	191° C.	218° C.	260° C.
Roasting time in mins. per lb.	28·8	20·5	19·8	15·4	12·9
Percentage loss of weight	6·8	15·8	18·7	25·8	30·4
Palatability, marks	78·0	76·3	75·6	71·7	68·2

Table I shows that the higher the oven temperature the greater was the percentage loss of weight. It should be noted that the palatability decreased as the oven temperature rose, a change which the detailed marks showed to be due chiefly to decrease in tenderness. Low oven temperatures, therefore, appear to have everything in their favour, but some compromise is necessary in order to obtain the desired roast flavour. A higher temperature must be employed for sufficient time to brown the outside of the joint.

Table III shows the effects of the degree to which beef is roasted; it is taken from a paper by Sartorious and Child,[7] who roasted the semitendinosus muscle in an oven at 150° C. to different internal temperatures.

TABLE III

	Raw	58° C.	67° C.	75° C.
Moisture content, per cent.	74·6	70·9	70·3	66·9
Loss in weight, per cent.	—	17·9	20·0	29·5
Diameter of fibres-microns	64·6	58·8	52·4	53·5
Shear force, lb.	34·3	26·3	21·8	24·4

The loss in weight increased and the moisture content decreased with increasing severity of cooking. The shear force, which is a measure of the toughness of the meat, also decreased with the severity of cooking up to the medium-done stage and then, with this particular cut, increased slightly when the roasting was continued to the well-done stage.

In a general way it may be concluded from these two tables that longer cooking times at lower temperatures favour the production of tender products. This is probably due in large part to the greater time available for the hydrolysis of the collagen of the connective tissue and is certainly in agreement with the accepted methods of cooking the various cuts of meat, for in general the prime, tender cuts are grilled or roasted and the tougher cuts are cooked by simmering in liquor, as in the preparation of stews or boiled silverside of beef.

Alexander and Clark[8] have carried out a careful and extensive study of the roasting of legs of lamb and mutton. They state that lamb is considered between medium and well done when the internal temperature reaches 76° C. and well done when the internal temperature reaches 83° C., at which stage it is probably preferred by most people. Their results confirm those already given for beef, namely that the percentage loss of weight increases with increase in the severity of roasting conditions and also with increase in the internal temperature reached. It is also of interest to note that these authors studied the effect of the length of the ripening period on the loss of weight during cooking. The left legs of 60 pairs were ripened for 2 to 6 days and the right legs for 8 to 18 days; both sets were roasted at 125° C., after searing for 20 minutes at 265° C., to an internal temperature of 76° C. The difference between the percentage losses of weight was small but significant, the figures being 15·6 per cent. for the shorter ripening period and 13·2 per cent. for the longer.

4. The Changes in the Composition of Meat on Cooking

Here it is proposed to discuss briefly how the changes in the composition of meat which occur on cooking affect its nutritional value. At the outset, however, one is faced with the difficulty that the composition of raw meat shows very great variations. Table IV gives some figures taken from a valuable publication by Chatfield[9] for wholesale cuts of beef and illustrates this point.

The author notes that for wholesale cuts there is an approximate relation between commercial grading and fat content and also that there is a close relation between the visible fat and the fat determined by ether extraction of a representative sample. It may also be noted that no matter what the fat content of any cut may be, the water–protein ratio remains constant at about 3·4 to 1. The tremendous effect of the fat content on the calorific value of the meat is shown in column 7.

TABLE IV

Edible portion

	Visible fat Per cent.	Water Per cent.	Protein Per cent.	Fat Per cent.	Ash Per cent.	Water protein ratio	Fuel value per 1 lb.
Round—							
Thin ..	8	71	19·7	8	1·00	3·6	680
Medium	13	67	19·3	13	0·95	3·5	880
Fat ..	16	63	18·7	17	0·90	3·4	1030
Very fat	22	58	17·4	24	0·82	3·3	1300
Rump—							
Thin ..	25	60	17·4	22	0·88	3·4	1210
Medium	33	53	15·5	31	0·77	3·4	1550
Fat ..	39	48	14·2	37	0·69	3·4	1770
Very fat	50	40	11·4	48	0·56	3·5	2170
Side—							
Thin ..	14	66	18·8	14	0·97	3·5	910
Medium	21	60	17·5	22	0·87	3·4	1220
Fat ..	27	55	16·3	28	0·79	3·4	1400
Very fat	38	47	13·7	39	0·65	3·4	1840

Clearly, therefore, to assess the effects of cooking on the composition of meat it is necessary to use cuts of comparable fat content or alternatively the effect of cooking on lean meat may be shown by expressing the results on a fat-free basis.

Rogers, Gillum, Kunerth and Pittman[10] give such analyses for raw beef and beef roasted in an oven at 150° C. to an internal temperature of 71° C. to 78° C. ; the joints as purchased ranged from 10 lb. to 15 lb. in weight.

It should be noted that the fat content of the raw and roast joints are much the same, but that on cooking, the protein content of the meat increases and the moisture content decreases, resulting in a marked change in the water–protein ratio.

TABLE V

	Fat per cent.		Protein per cent.		Water per cent.		Ash per cent.		Water / protein	
	Raw	Roast	Raw	Roast	Raw	Roast	Raw	Roast	Raw	Roast
Clod	18·2	22·0	21·1	25·3	58·8	47·2	0·96	1·06	2·8	1·9
Ribs	31·0	32·6	19·8	31·9	48·3	31·1	0·81	1·06	2·4	1·1
Top round ..	6·6	9·0	24·1	30·6	68·1	60·7	1·16	1·12	2·8	2·0

Grindley and co-workers[11] also made analyses of the raw and cooked beef used in their experiments on the losses that occur on cooking meat, the results of which are summarized in Table VI.

TABLE VI

	No. of samples averaged	Water per cent.	Total protein per cent.	Fat per cent.	Ash per cent.
Raw beef	8	73·2	18·8	4·9	1·1
„ „	12	69·1	17·8	10·9	1·0
Beef boiled 3 hours ..	14	57·1	34·6	6·5	0·7
„ „ 5 „ ..	17	57·9	29·9	11·8	0·6
„ roasted	2	66·6	22·3	7·5	1·2

The results given in Table V and VI show that the nutritional value of cooked meat is greater than that of raw meat by virtue of its reduced moisture content and increased protein content.

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Part VI

FISH AS FOOD

(*Papers read at a meeting on 24th February,* 1943)

CHAPTER XXII

THE BIOLOGY OF THE SEA FISHERIES

By R. S. Wimpenny

This chapter is an attempt to outline the biological origin of our food fisheries, to pick out the essentials of a complex story and to regard the sequence of events crudely and simply, as if they were a series of factory processes. To do this it is proposed to describe the lay-out and structure of the system of organic production that ends in the commercial landing of fish and shellfish, and then the conditions that govern the system and may help to produce the quantitative and qualitative optimum yield of human food.

Fundamentally our sea fisheries depend upon the ability of small floating algæ and some flagellates to carry out photosynthesis in the presence of a sufficient supply of the inorganic salts necessary for their growth. We may conveniently call this group "producer" plankton. The most important class of these organisms is the diatoms, vast masses of whose tiny single or connected cells may be so abundant as to cause a perceptible clouding of the sea in certain places. The growth of diatoms and other producers in the microplankton is only possible in the upper photic water layers, and then only in the presence of adequate nutrient salts. It frequently happens that the surface layers of the sea in which this growth is taking place may become stable and isolated from the deeper water. In these circumstances the producer plankton may eventually exhaust some nutrient salt such as nitrate or phosphate, which occurs in very small quantities (30 mg. to 200 mg. per cubic metre), so that the flowering dies away. The work of Atkins[1] and Harvey[8] suggests that this may regularly occur in the off-shore waters of the North Sea and the entrance to the English Channel. Here thermal stratification isolates the upper water layers from about May until October, when they become cooler than those below them and vertical mixing takes place. In these areas there is a spring and early summer outburst of diatoms, followed by another and generally smaller one at the time of the autumn turnover.

Where nutrient salts are being constantly brought up to the photic zone, as in the shallow water near the coast and in parts where there is a constant up-welling of deep ocean water to the surface (i.e., off the coast of W. Africa and west of S. America) or where they enter the sea at the mouths of great rivers, an unusually heavy and continuous area of production may be found. Apart from the special areas just mentioned, producer plankton does not show heavy crops in the warmer waters of the world and production appears to be more continuous and lighter than in higher latitudes. This is thought to be due to the fact that there is no big autumn and winter mixing of the photic layers of the sea with those deeper down and that the more intense light penetrating deeper into the water is available for photosynthesis at all seasons, permitting no chance of the breakdown and accumulation of inorganic end-products and nutrient salts in the upper water layers. Towards the poles an increasing period of winter rest is followed by increasingly vigorous outbursts of producer plankton. Data taken from various sources show a relative lack of phosphates near the surface in warmer seas while there is an abundance at high latitudes; it only remains to say that even after the end of a big outburst of diatom growth in the Antarctic it has been found that there has been no exhaustion of phosphate, so rich is the supply. This generalized picture for phosphate is probably broadly similar to that for the other manurial salts, and it is possible that some of these others may be in such short supply as to terminate diatom growth at certain times and places, e.g., in the Antarctic where phosphate is not used up.

The producer plankton, which I have been discussing hitherto, is composed of small cells from $2\mu.$ to $50\mu.$ in diameter and supplies the food of a variety of consumer organisms of sizes from roughly 0·5 mm. to 50 mm. The latter may be divided into the zooplankton, composed of animals swimming among the producer plankton, and the filter and detritus feeding animals of the bottom fauna, which live beneath. Among the zooplankton are to be found the floating eggs of our principal food fishes, and it is to be noted that when these are hatched out and the larval fish have exhausted their yolk sac, their first food consists of the small cells of the diatoms. Of the bottom feeding animals which feed almost entirely on diatoms, and depend on diatoms and flagellates alike for the survival of their brood and their fattening as adults, important edible molluscs such as the oyster, mussel, and cockle are to be noted. The zooplankton animals in their turn form the food of post-larval food fishes, some adult food-fishes (herring, mackerel and sprats), the largest organism now living (the blue whale of the Antarctic) and an immense variety of other pelagic or littoral animals, some of which are the chief food of our adult food fishes. The zooplankton, therefore, forms an important link between the latter and the producer plankton. The individual length of life of some of the most important elements of the zooplankton may be from 2 to 10 months, and this gives the zooplankton population a persistence not shown among diatoms, vast flowerings of which may entirely disappear in a week or two. In our latitudes, the zooplankton appears to build itself up on the spring and early summer production of diatoms, rising to a summer maximum and remaining in some strength until the autumn, when after following up the second diatom flowering it diminishes in numbers and does not increase again until the following spring. This persistence of the zooplankton for a considerable period after the disappearance of the spring diatom maximum may be thought of as a "bank" or store, perpetuating the initial outburst of organic production and making it available for larger consumers over an extensive period during which it would otherwise have been completely broken down and not available. Towards the poles life-histories are longer and the zooplankton carry-over from a more extensive diatom flowering is likely to be greater.

The more vigorous production indicated as the poles are approached is apparent not only in the two communities of plankton but also in the published landings from the commercial fisheries. This is shown in the following list of countries north and south of 30° N. and 30° S. Latitude and for the zone between:

World yields in thousands of tons

	Fishery yields		Whale oil	Total
Japan	4635·0	10,028.3	14·6	10,042·9
U.S.A., Alaska and Canada	1983·0			
N.W. Europe	3243·0			
Mediterranean	167·3			
Mexico	6·3	428·5	9·8	438·3
Hawaii	4·5			
S. India	141·5			
French Indo-China	160·0			
Straits Settlements	65·1			
Fiji	1·4			
Peru	4·0			
Union of South Africa	15·0			
Australia	30·7			
Chile	19·9	39·9	4092·7	4132·6
New Zealand	20·0			

Like the plankton, most of the important food fishes have a stage during which they float, first passively as eggs and then more or less purposefully as young fish, feeding first upon the phytoplankton and later upon the zooplankton. As they grow up the type of food changes, cod, haddock, and whiting feeding on hermit crabs, other medium-sized crustacea, small fish, herring, and sprats. Fish that live in more intimate contact with the sea floor, plaice and other flat fish, feed on molluscs, burrowing worms, and so on. Pelagic fish, such as the herring, mackerel, and sprat, may continue to support themselves largely upon the zooplankton as adults, and in so doing resemble the balein whales. It is to be noted that all these species upon which we rely for food (and, indeed, most other species of fish) are carnivorous; it is only organisms of very small size, or filter feeders, such as are met with among shellfish, that are able to be herbivores in the sea. This state of affairs contrasts sharply with conditions on land, where our meat animals are all herbivores. The great commercial fisheries are not in or over deep water, but on the shoaler banks and shallow waters down to a hundred fathoms or so, and where the plankton production is greater than over the deep water of the oceans. Off N.W. Europe there are considerable shallow areas of this sort and the chief method of exploitation is to catch the fish that live on the bottom by a netting bag or "trawl" dragged over the ground by a steam trawler. Of the twenty-eight market categories returned for this type of fishing, cod, haddock, coalfish, and plaice make up the greater part, cod alone representing over 40 per cent. of the 15,148,845 cwt. of demersal fish landed by British fishing vessels in 1938. Fish that swim in the upper water layers, such as the herring, of which 5,387,202 cwt. were landed in 1938, are caught by curtains of netting, whose tops are supported on the water by a series of buoys. Two or three miles of this netting may be laid by one boat for one night's fishing. Nets of this kind are called drift nets. In concluding this brief description of the sea fisheries, it is to be pointed out that although the best catches are made in the northern part of the European area, a greater variety of species are landed from the south.

The production of food fish has already shown that it is liable to considerable fluctuations, due to causes outside man's control. For instance, it quite commonly happens that one year-group of fish may enjoy inordinate success, and as it comes into the commercial catch it may favourably affect the yield, or the whole fountain of production may die down, as it appears to have done in the Plymouth neighbourhood since 1931. In this instance the available nutrient salts and the young fish have all diminished sharply, the herring fishery having disappeared from lack of recruits.[10] In the North Sea there appear to have been cycles in the incursion of oceanic water capable of giving rise to outbursts of plankton production, and in the far north there has been a great extension of the fishable area owing to the spread of warmer water in the northern hemisphere.[14] This has given rise to very considerable increases in the landings of cod in recent years. In view of the proportion of cod in the landings, this great natural fluctuation has had a most important effect on our fisheries.

Let us turn now to man's effect on the fisheries. In this connection it may be noted that in 1866 a Royal Commission examined the effect of the commercial fishery on the fish stocks, but came to the conclusion that this was negligible and recommended the abolition of all restrictive legislation. Most of the fishing was then in the North Sea and was practised by sailing vessels with beam trawls. Since that time, however, the introduction of steam vessels of greater and greater power and efficiency and the greater catching power of the improved trawls, first the otter trawl and then its Vigneron-Dahl improvement, have produced an enormous increase in the landings and the employment of more and more vessels going further and further afield, until just before the war our main source of trawl-fish was the Arctic. A falling-off in the catch of the waters nearer home was noticed by the fishing industry before the end of the last century, and by 1902, when the International Council for the Scientific Exploration of the Sea was formed, the marine biologists of several European countries had turned their attention to this matter with special reference to the plaice fishery of the North Sea. It was, however, the importation of a partial holiday of four years on the North Sea fishing, as a result of the 1914–18 war, that really clarified matters. The subsequent sharp rise in the catch was followed by a steady fall, when the large number of trawlers that were commissioned after the last war continued their exploitation of the North Sea fishery at the same massive level in the years that followed. A consideration of this sequence produced the first clearly defined accounts of over-fishing made in this country by E. S. Russell[12] and then, with the addition of a numerical computation, by Graham.[4] Briefly, the position was as follows. Although the gross annual landings of fish increased rapidly towards the end of the last century and the beginning of this, and although these total landings have continued their rise in recent years, this increase was more apparent than real, having been brought about by the progressive extension of grounds and perfecting of gear already mentioned. A study of the better range and more exact statistics now available showed that the North Sea, and, indeed, any other long-exploited grounds, were falling off before the war and that, following a sharp increase after the war, the decline on the older grounds was continued.

This course of events was explained on the Over-Fishing Theory by the assumption that there is in the sea a stock of fish in steady equilibrium so that those that are caught (C) and those that die natural deaths (M) are replaced by the recruits that grow to a catchable size in any given period (A), plus the increases in weight of the fish of catchable size (G). In algebraic form : $A + G = C + M$.

Under the conditions of over-fishing that had been discerned, the tendency was for the establishment of an equilibrium at too low an average weight of fish taken. To reach an optimum return the intensity of fishing would have to be relaxed in order to allow the fish to reach a higher average age and weight. At the other extreme too little fishing would not catch fish in sufficient numbers to give the necessary yield in weight. As a result of considering the various effects of a partial reduction of fishing in the war of 1914–18, Graham has constructed a sigmoid curve showing the weight of the stock of food-fish in the North Sea at different levels of fishing. In doing so he assumes first that there is a limit to the weight of stock an area will support, and secondly, that the rate of natural increase $(A + G - M)$ is directly proportional to the difference between the weight of the stock at the moment and the maximum weight the area will support. The stock may be stabilized at any level by a catch equivalent to the rate of natural increase. Bearing in mind that the stability of the upper stock limit and freedom from fluctuations are assumed, it is to be observed that the sigmoid curve indicated that in 1914 fishing was proceeding a little beyond the rate for optimum yield, which comes at the steepest part of the curve. In 1935 a greater effort was producing less, and from his workings, Graham has made the rough estimate that 15 per cent. more fish could be obtained with 25 per cent. less effort. Here then is one way by which a massive contribution may be made to the quantitative optimum of demersal fish—reduce trawling. There is at present no clear evidence that our great herring fisheries are being over-exploited and that the same yield of these pelagic fishes could be better obtained by a relaxed effort.

We may now turn from factors known to be affecting production to examine those that are merely potential in this connection, but to which we might look for further development. First it is to be noted that the available organic matter in the sea, as shown by the change of pH in digested samples, or by the annual changes of phosphate content and similar methods, considerably exceeds the maximum estimates that may be built up by the most refined methods of direct counting and culture. This balance still remains to be satisfactorily explained. Next we have to remember that, as the present yield we obtain from the sea is derived from the plankton, it should be possible to obtain a greater return of organic matter by making direct catches of these organisms. Of the two plankton communities we need examine, the diatoms, owing to their small individual size, offer a very great mechanical problem in connection with their filtration and capture in commercial quantities. Moreover, they contain a high percentage of ash, a substantial amount of silica and, as I can vouch for by experience, are not particularly palatable as a dried powder or flour. Zooplankton, on the other hand, will dry to produce a rather attractive and palatable "shrimp paste" with a fat content of 10 per cent. to 30 per cent. of the dry weight and capable of possessing a satisfactory content of vitamin A, which is absent from diatoms. At the right time and place considerable quantities of zooplankton may be caught in a stramim net with a two-metre mouth towed behind a boat, and it has in fact been suggested that batteries of such nets (Hardy[6]) might be anchored in Scottish lochs where there is a good run of tide, in order that the zooplankton may be caught on a commercial scale. The draw-back to exploiting the potentially greater yield to be obtained from the plankton is that it is inconveniently spread in time and season and that its small size makes it difficulty to capture. The food-fish, on the other hand, do this job for us and provide us with a population that remains much steadier at all seasons.

Concentrations of both producer and consumer plankton very much greater than these found in nature may be cultivated by the addition of suitable nutrient salts to the water. Gross,[5] for instance, gives 50,000 producer organisms per litre as the maximum he knows to have occurred in nature at the optimum season, but he has been able to maintain cultures at a level of 50,000,000 organisms per litre at any season of the year. Petterson[11] at Göteborg has been attempting plankton culture of this kind on a bigger scale in a large shaft-like tank, and the results of his work will be awaited with interest. Deliberate efforts to farm fish or shellfish have been made, and of these carp ponds may be noted as having been established for hundreds of years. I give below the yield from such efforts at cultivation compared with those of uncultivated fisheries, potential and observed plankton crops and one form of production on land.

WET WEIGHT IN KG. PER HECTARE PER YEAR

Beef[9]	83·6
Carp ponds[9,2]	65·5–950·0
North Sea[9]	17·3
Cultivated mussel beds[9]	8000·0
Uncultivated mussel beds[9]	4000·0
English Channel minimum plankton crop estimate[7]	14,500·0
South Georgia minimum plankton crop estimate[7]	30,750·0

WET WEIGHT IN KG. PER HECTARE—STANDING CROP

North Sea Hensen net plankton[3]	150–200·0

This list and the one given earlier in this chapter, when the relation of yield to latitude was being discussed, show that greater yields may be expected from organisms linked into or constituting a simple food chain and from communities at higher rather than lower latitude conditions. The maximum yield that a ground can support will thus vary according to the structure of the community and probably the temperature. These circumstances must be seriously taken into account when making calculations of the optimum yield based on the sigmoid curve utilized by Graham. It is to be pointed out in this connection that, while over-fishing has been demonstrated for most of the trawl-fish which are linked in a somewhat complex food chain, this is not so with the herring, which feeds for the most part directly on the zooplankton. The interrelations I have just been dealing with belong to ecology, and it is relevant to mention here two principles that cover the subject and have been dealt with elsewhere (Wimpenny[15]). The first is that the number and mass of organisms tend to vary inversely with the number of species living in any given habitat. Where the habitat conditions remain otherwise the same, a higher temperature and a lower food supply favour specific differentiation and a reduction of the numbers and total mass of organisms. The second is based on Bergmann's rule, which lays down that the size of warm-blooded animals increases with latitude. This may be extended to all other animals whose assimilation is not suspended by hibernation, or other similar effects, and by seasonal lack of food. The last-mentioned factor causes periods of cessation of growth in littoral and many pelagic animals of higher latitudes and probably results in many examples of fish species of the largest size being found in warmer seas.

Let us also turn for a moment to the question of quality. In the producer plankton there is a preponderance of diatoms towards the poles and these diatoms elaborate fat as a metabolic end-product in contradistinction to the carbohydrate-forming flagellates, which are relatively more abundant in warmer seas. Data in my possession suggest that for the whole coarse-net plankton there is a higher percentage of fat at higher latitudes. Fat content is of great importance in determining the condition of fish and it is worth while to examine what is known of this quality in the herring. There is a seasonal variation in the fatness of the herring, and this is related to its habits. In the southern North Sea the food of the herring consists largely of zooplankton, and it has been shown that this feeding rises to a maximum in May and then dies away as the fish approach the time of spawning (Savage[13]). The percentage of fat in the Flamborough-Dogger Bank plankton for various months of the year 1935, together with estimates of the fat at intervals during the herring season at Shields and Lowestoft, has shown that the fat-content of the plankton rose to a maximum slightly earlier than that of the herring, and it seems fairly clear that the one had been built up from the other.[16] The importance of understanding this life-cycle, and its relation in helping to select the proper season for fat herring in the right condition for canning or other forms of processing, is obvious.

Another and curious relation of herring fat-content, suggested by observations on individual variation, refers to lunar periodicity.[16] It has long been known that the East Anglian herring concentrate in dense and active shoals at the time of the full moon. Bearing this fact in mind, when I had occasion to investigate the individual variation in fat-content as the result of a complaint by a local canner, I chose my samples of ten as near as possible to the times of the new and full moons. The work was carried out during the autumn fisheries of 1934, 1935 and 1937, and showed that there was considerable variation in individual fat-content for herring muscle, but that these variations did not seem to be due to the age, length, or sex of the individuals constituting the samples. On the other hand, although it was evident that the scope of the sampling was not adequate to the purpose, the results indicated by the dispersion of values in 1934 and 1937 that there may be a greater spread at the time of the full moon and that at the time of the new moon, when the shoals are more quiescent, the fat values are more uniform. Finally, there is to be mentioned another possible source of variation in the fat-content of herring muscle that has not been investigated. This is the diurnal variation. The herring regularly approaches the surface of the sea at night and in doing so is following the upward movement of many of the zooplankton animals on which it feeds and which themselves often feed upon the diatoms more actively at night. While there is no information on this point concerning the herring, I have found evidence of diurnal variation in the fat-content of other organisms and it is obviously desirable that the condition of the herring should be investigated in this respect.

The indications given in this chapter suggest the following moral. This is that, for the optimum exploitation of the sea fisheries, either by farming or by fishing in the open sea, we need a knowledge of ecological laws that are themselves a bridge between the study of the natural history of a variety of living organisms on the one hand and important non-vital principles of chemistry and physics on the other.

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CHAPTER XXIII

THE CHEMICAL COMPOSITION OF FISH

By G. A. REAY, C. L. CUTTING, and J. M. SHEWAN

QUANTITIES AND TYPES OF BRITISH FISH

This chapter deals with the chemical composition of the edible portion of fish in the raw state, not taking account of vitamins, minerals and trace elements which are discussed by Lovern[1]. Despite a wealth of data on foreign fish, consideration has been limited to British species, except for a few comparative analyses of the same or related species found abroad.

The great variety of species presents a complication in dealing generally with fish as food. Some classification must be adopted to show the relative quantitative importance of species, and this is done in Table I for the demersal and pelagic marine fishes.[2,3] The scheme adopted has, apart from the "Miscellaneous" group, considerable basis in zoological and, as will be seen later, to some extent in biochemical relationships. Amongst the demersal or "white" fishes, the preponderance of the *Gadidae* is striking, in particular the contribution made first by the cod and then by the haddock. Next in order come the "flat fishes," with the plaice greatly predominating, but only equivalent to some third part of the landings of the haddock. This group contains most of what are at present regarded as the choicest species, but as McCance and Shipp[4] justly remark, this has no relation to nutritive value. Each about half as important as the flat fishes are the Elasmobranchs and the "Miscellaneous" group in Table I. Amongst the pelagic fishes, the herring is by far the predominant species, being comparable in importance with the cod.

Of the freshwater fishes, only imported canned salmon is comparable with the marine species in the quantities consumed. Of home-caught freshwater species, only salmon[5,6] and eels,[2] both of which spend a proportion of their life in the sea, are widely eaten in this country, although in countries with large rivers and lakes the freshwater fisheries are of considerable economic importance, and on the Continent are augmented by pisciculture. Carp is the fish most usually domesticated and large farms are kept going on towns' waste, with quite economic returns[7]. Efforts are now being made to organize a commercial fishery for perch in some of the

TABLE I. BRITISH LANDINGS. 1938 STATISTICS

	Gadoids	Flatfishes	Elasmobranchs	Miscellaneous	Pelagic	Freshwater	Crustacea	Molluscs	Thousands of tons	Per cent. of total
1	Cod	—	—	—	—	—	—	—	361·0	30·5
2	—	—	—	—	Herring	—	—	—	288·6	24·5
3.	Haddock	—	—	—	—	—	—	—	149·8	12·7
4.	—	Plaice	—	—	—	—	—	—	43·5	3·7
5.	Hake	—	—	—	—	—	—	—	34·2	2·9
6.	Saithe	—	—	—	—	—	—	—	30·9	2·6
7.	Whiting	—	—	—	—	—	—	—	30·0	2·5
8.	—	—	Skates	—	—	—	—	—	22·1	1·9
9.	Ling	—	—	—	—	—	—	—	12·0	1·0
10.	—	—	—	—	—	—	—	Cockles	10·8	0·9
11.	—	—	—	—	Mackerel	—	—	—	10·1	0·9
12.	—	—	—	Catfish	—	—	—	—	9·9	0·8
13.	—	—	Dogfish	—	—	—	—	—	8·2	0·7
14.	—	—	—	—	—	Salmon	—	—	8·1	0·7
15.	—	Lemon soles	—	—	—	—	—	—	8·0	0·7
16.	—	—	—	Monkfish	—	—	—	—	7·4	0·6
17.	—	—	—	—	—	—	—	Mussels	6·6	0·6
18.	—	—	—	—	Sprats	—	—	—	6·2	0·5
19.	—	—	—	—	—	—	Crabs	—	6	0·5
20.	—	Halibut	—	—	—	—	—	—	5·2	0·4
21.	—	Megrims	—	—	—	—	—	—	4·8	0·4
22.	—	Dabs	—	—	—	—	—	—	4·3	0·4
23.	—	—	—	Redfish	—	—	—	—	3·8	0·3
24.	—	Turbot	—	—	—	—	—	—	3·3	0·3
25.	—	Soles	—	—	—	—	—	—	3·2	0·3
26.	—	Witches	—	—	—	—	—	—	3·2	0·3
27.	—	—	—	—	—	—	—	Oysters	3	0·3
28.	Tusk	—	—	—	—	—	—	—	2·9	0·2
29.	—	—	—	Gurnards	—	—	—	—	2·7	0·2
30.	—	—	—	Congers	—	—	—	—	2·7	0·2
31.	—	—	—	—	—	—	Shrimps	—	2·4	0·2
32.	—	—	—	—	Pilchards	—	—	—	2·3	0·2
33.	—	—	—	—	—	—	Lobsters	—	2	0·2
34.	—	—	—	—	—	—	—	Whelks	1·8	0·2
35.	—	—	—	—	—	Eels	—	—	1·8	0·2
36.	—	—	—	—	—	—	Prawns	—	1·6	0·1
37.	—	—	—	Bream	—	—	—	—	1·4	0·1
38.	Pollack	—	—	—	—	—	—	—	1·2	0·1
39.	—	—	—	—	—	—	—	Winkles	1·0	0·08
40.	—	Brill	—	—	—	—	—	—	0·8	0·07
41.	—	Flounders	—	—	—	—	—	—	0·4	0·03
42.	—	—	—	—	—	—	—	Scallops (Clams)	0·4	0·03
43.	—	—	—	—	White bait	—	—	—	0·3	0·03
44.	—	—	—	—	—	—	Nephrops	—	0·1	0·01

TABLE I—*Continued*. BRITISH LANDINGS. 1938 STATISTICS

	Gadoids	Flatfishes	Elasmobranchs	Miscellaneous	Pelagic	Freshwater	Crustacea	Molluscs	Thousands of tons	Per cent. of total
45.	—	—	—	Dory	—	—	—	—	0·1	0·01
46.	—	—	—	Squids	—	—	—	—	0·05	0·005
47.	—	—	—	—	Grey mullet	—	—	—	0·04	0·004
48.	—	—	—	Red mullet	—	—	—	—	0·03	0·003
49.	—	—	—	—	—	—	Crawfish	—	0·02	0·002
50.	—	—	—	—	Smelts	—	—	—	0·005	0·0005
—	—	—	—	Mixed and other kinds (British)	—	—	—	—	8·2	0·70
—	—	—	—	Foreign (all kinds except haddocks, cods and plaice)	—	—	—	—	21·6	1·83
—	—	—	—	Livers	—	—	—	—	32·1	2·79
—	—	—	—	Roes	—	—	—	—	2·0	0·17
—	—	—	—	—	—	—	—	Shellfish (mixed)	6·1	0·52
Total gadoids									622·0	52·6
„ flatfish									76·7	6·5
„ elasmobranchs									37·7	3·2
„ Miscellaneous									13·3	1·2
„ unclassified, livers and roes									71·3	6·0
Total demersal									821·0	69·5
„ pelagic									307·6	26·1
Total marine wet fish									1128·6	95·6
„ freshwater									9·9	0·8
„ wet fish									1138·5	96·4
„ crustaceans									12·1	1·0
„ molluscs									23·6	2·0
Total shellfish									41·8	3·6
Grand total									1180·3	100·0

larger British lakes, in which they are a pest. Up to date, small fry have been canned on a small scale with fair success. In the two years 1941 and 1942, 56 tons were removed from Windermere and nearly half a million tins of "perchines" produced.[8] However, this represents not only the annual crop, but also a reduction in the stock. The total stocks of trout and coarse fish have been estimated as only about 8000 tons, with an optimum yield of not more than 2000 tons annually.[9] Steps are being taken to improve the fishery for eels by releasing elvers in the rivers.

The figure for shellfish mainly represents inedible mineral matter.

The total weight of fish landed in 1938 was, therefore, just over a million tons.

Edible Portion

For practical purposes the edible portion of fish may be taken as being roughly equivalent to the commercial fillet, which consists mainly of muscle, with frequently a proportion of skin, which, however, is not always eaten. As compared with beef, lean fish has apparently a small amount of connective tissue, and in the fatty fish, of which the flesh seasonally becomes infiltrated with fat, there is no clearly marked and easily separable fatty tissue, as there is in meat. It is true that fat content may vary throughout the length of the fish, and is apparently particularly high along the red lateral band in the fatty fishes, but this is of some importance only in the large fishes, such as halibut or salmon, where different cuts might contain different amounts of fat. Apart from skin then, which is easily separable—but not in certain thin-skinned fishes such as herring—and could be separately accounted for, if thought necessary, the edible portion of fish has necessarily to be taken *en bloc* —in contradistinction to that of meat. The fillet represents, of course, the minimum edible portion.

Some fish, particularly smaller ones, are bought with head and bone; if they are carefully "picked" on the plate, the yield of flesh is raised. Some larger fish, e.g., turbot, are sold and cooked whole, or sold in cuts. Also a considerable quantity of fish reaches the consumer, such as processed salted or smoked, or usually having lost only water. On the other hand, the fillet, which has become so popular in the important classes of fish, can be taken as the most useful general form representing "edible portion."

The "white" fishes are nearly all gutted at sea, the viscera being thrown away, with the exception of the liver, which is kept when suitable for oil extraction, and the gonads, which are kept in the season for separate sale as food. In the cod and haddock, the chief "white" fishes, the proportion of viscera appears from figures obtained at the Torry Research Station usually to be of the order of 6 per cent. to 12 per cent., of which the liver may represent about half. At spawning time the gonads may account for about 15 per cent. of the weight of the whole fish, the figure for total viscera rising to some 22 per cent.

For the important class of *Gadidae* the "landed weight" recorded in Fisheries' Statistics is the weight of the completely eviscerated fish, and estimates of "edible portion" are most conveniently based on this. "Landed weight" for the flat fishes does not include viscera, which appear to account for some 1 per cent. to 5 per cent. of the ungutted weight, but includes the gonads, which are not readily removed by the usual gutting operation and may amount to as much as 20 per cent. of the weight of the fish at spawning time. This is likely to cause some fluctuation in the proportion of "edible portion," but no clear data exist to show its extent. Dogfish are often landed ungutted, and skates and rays simply as "wings." The miscellaneous fish are usually gutted at sea. Pelagic fish—herrings, mackerel, sprats, and so on—are always landed in the ungutted condition, although herring are now frequently filleted before sale, the roes and milts being sold separately.

In Table II*a* are shown mean figures for the "edible portion," i.e., the fillet as removed commercially with and without skin, for some of the more important species of white fish. Previously recorded figures have not been included and the values given are based on measurements made from time to time by the staffs of the Marine Laboratory of the Fishery Board for Scotland and of the Torry Research Station of the Department of Scientific and Industrial Research. No attempts have yet been made to correlate variations in "edible portion" with size, age, maturity, and so on. In Table II*b* are shown figures for the "edible portion" of the herring at various stages of maturity, the measurements having been carried out at the Torry Research Station. Here the "landed weight" is, of course, the "ungutted weight" and the increased food available as gonads is shown in the table.

In the greatly preponderant species of "white" fish, viz., the cod and the haddock, the yield of edible material is in the region of 41 per cent. to 42 per cent. and with skin 44 per cent. to 47 per cent. Plimmer[10] gives values of 54 per cent. to 65 per cent. for the yield of flesh plus skin, but his dissection was probably more thoroughly anatomical than commercial filleting. In skinning and filleting cod of average weight, about 10 lb., and taking some little extra care to

TABLE II

Edible proportion of british fish

(*a*) *Demersal fish*

Edible portion (fillet) as percentage of landed (i.e., gutted) weight

Species	Without skin No. of fish	Without skin Per cent.	With skin No. of fish	With skin Per cent.
Cod	563	42	14	44
Haddock	110	42	27	47
Whiting	20	38	10	44
Hake	2	64	2	69
Ling	7	51	1	52
Plaice	18	44	4	61
Lemon sole	64	52	36	58
Catfish	4	38	—	—
Angler	7	25	—	—

(*b*) *Herring*

Maturity	No. of fish	Edible portion (fillet) as per cent. of landed (i.e., ungutted) weight	Edible portion including milt or roe
Immature	26	57	—
Spent	25	55	—
< ¼ to ¼ ripe	73	58	—
¼ to ½ ripe	28	54	66
¾ to ¾ + ripe	25	51	69
Ripe	6	47	69
Weighted average		53	69

(*c*) *Freshwater fish*[10,11]

Species	No. of fish	Edible portion as per cent. of the weight at capture
Salmon	1	64
Sea trout	4	63
Brown trout	1	68
Eel	1	59
Perch	∿300	33
Pike	∿12	43

(*d*) *Shellfish*[4,10,11,12]

Species	No. of samples	Edible portion as per cent. of weight in shell
Crustaceans—		
Crab	4	40
Lobster	3	44
Prawn	1	46
Shrimp	1	47
Molluscs—		
Oyster	42*	11·8
Mussel	2	28
Scallop	1	18
Whelk	1	42
Periwinkle	1	22

* Average weight 2·01 oz. (about 2100 specimens).

trim the flesh from the bones covering the gill region (termed by the trade the "lugs"), it has been found possible, when dealing with quantities of the order of ½ ton of fish at a time, approximately commercial conditions, to obtain total yields of 43 per cent. to 46 per cent. edible. There is also a small amount of flesh left on the head. Hake, possibly because it has a relatively smaller head and a more cylindrical body, appears to afford the highest yield among the *Gadidae*, with ling, also an elongated fish, next in order.

The plaice and lemon sole have a higher yield than cod and haddock, particularly when skin is left on, of which there is a larger proportion owing to the higher ratio of surface to volume in flat fish. Trade estimates show that as a class the flat fishes afford this higher yield, except the witch and megrim, which more nearly resemble the cod and haddock. Fifty per cent. is taken as a common "all over" figure by the trade for flat fishes.

According to trade information, skate "wings" are some 40 per cent. to 50 per cent. edible and this may also be taken as a fair range for dogfish. The average yield from the miscellaneous fishes is probably of the same order except in species with peculiar morphology such as the angler (or monk fish), which has an inedible portion of about 75 per cent., but only accounts for about 1 per cent. of the total demersal fish landed. Catfish is shown in the table to have 38 per cent., whilst the gurnard probably yields as a rule something under 40 per cent., according to both Plimmer and trade estimates.

The herring data show that about 55 per cent. is a fair average figure for the yield, expressed on the ungutted weight. The effect of maturity is interesting, showing a fall to 47 per cent. in the mature fish on the one hand, and an increase in total edible matter up to 69 per cent. when gonads are included.

Amongst other pelagic species, also normally landed ungutted, mackerel are reported to lose about 8 per cent. on evisceration[13] and the edible portion amounts, as with herring, to about 45 per cent.[14] and 1 cwt. of grey mullet (*Mugil chelo*) has been found to lose 14 per cent. on gutting, while heading and filleting result in a yield of 55 per cent. of the gutted weight or 43 per cent. when skinned, i.e., 38 per cent. on the ungutted weight.

With freshwater fish (Table II*c*), the landed weight, of course, includes the viscera. With the migratory species, the yield of flesh depends on the stage in the sexual cycle, the fish being very thin about spawning time, when they are not feeding. There is a very large wastage factor in all shell fish (Table II*d*). The wastage factor is known with greater precision for the oyster than for any other species of edible fish, owing to the work of Russell.[12]

Taking Plimmer's figure of 53 per cent. for the carcase in relation to the live weight of the ox and allowing 20 per cent. for bone, the yield of edible matter is about 42 per cent. The yield of flesh from fish thus compares quite favourably with that of meat from the live carcase.

Fat, Protein, and Water Contents

Coming now to the composition of the raw flesh of fish (for the effect of cooking, see Baker[15]), Table III shows the ranges of values found in the literature and by analysis at Torry Research Station for the content of water, fat, and protein in the different classes. One feature that makes the literature on the proximate analysis of fish very confusing is that published tables incorporate the results of earlier workers. Thus, the work of Atwater,[14] which, although scrupulously careful, was done in the 1880's before Kjeldahl's method for determining nitrogen had ousted the soda-lime method, frequently recurs even to-day. There is also the difficulty, not found with edible, domesticated, warm-blooded animals, that fish of the same common name analysed in other countries may belong to different species or even different genera. Tables III*a* and III*c* include values of other workers, III*b* deals separately with our own determinations, and III*d* is entirely and III*e* almost entirely based on previously published data. The column headed "number of samples" gives the maximum and minimum number of figures giving the range of variation of the different constituents.

The figures for protein have been arrived at by multiplying the total nitrogen by the conventional factor 6·25. For the major protein, myosin, in fish and lobster, the factor is now thought to be 6·0, the earlier lower figures for percentage of nitrogen being probably due to inadequate extraction of fatty material[16] In the muscle of marine fishes, the non-coagulable nitrogenous extractives (see Table IX), only a small proportion of which can be utilized, cause figures for protein based on total nitrogen to be 10 per cent. to 20 per cent. too high, and even more with elasmobranchs, which contain greater quantities of urea and trimethylamine oxide. Although, therefore, it is impossible to arrive at very precise estimates from the figures given, they nevertheless provide some idea of the extent of variation within and between species.

The results for demersal species (Table III*a*) reveal that the gadoids closely resemble one another in chemical composition, the fat content being significantly lower than in any of the other groups. The flat fish contain more fat than the gadoids, and there appears to be a considerable seasonal variation in the fat content of the halibut and possibly the witch.* The remaining fish contain 2 per cent. to 5 per cent. of fat with few exceptions and show great similarity in constitution.

The first equations for herring in Table III*b* are based on two series of 145 and 78 determinations respectively, some already published,[23] which were made on fish from various grounds by two teams of workers, under Lovern and Reay, over the course of several years.

There is very little correlation between the fat and dry fat-free residue. Water and fat, if not completely interchangeable, are much more nearly inversely proportional than in beef, and the range of fat content covered is wider than with beef.[27]† The existence of a number of races of herring with different spawning times (e.g., "autumn" or "spring" spawners) means that fish in a quite different state of maturity and widely varying fat content can be caught simultaneously.[23] It has been reported that fat content increases with length in the small Clyde herring over the range 10 cm. to 14 cm.,[24] and that the fat-content of adults at any given stage of maturity increases with age.[25] The highest figures of Lovern and Reay for fat content, 22·4 per cent. and 22·3 per cent., were for herring, less than half ripe, caught off Aberdeen and Wick respectively in the second half of July. The lowest, 0·4 per cent. and 0·9 per cent., were obtained for spent females caught on the Viking Bank in April. The other values were fairly evenly distributed amongst intermediate percentage groups. Herring caught off the Isle of Man during the second half of July have been reported with as much as 41·8 per cent. of fat and as little as 35 per cent. of water,[26] but this is early work which there is reason to doubt. Out of more than 100 values taken from the literature, 46 selected ones, of which 41 had more than 10 per cent. of fat, give a different picture when

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* Wilson[22] found histologically in many flat fishes and in the John Dory that adipose tissue is developed in definite regions, principally beneath the dorsal and ventral unpaired fins, and associated with the skeleton, particularly the vertebral column, whilst little is deposited along the lateral line beneath the skin. In the flounder, which leaves estuaries for the sea to spawn, the fat depots are depleted during the spawning period, and fat cannot then be stained in the adipose tissue, which is in a collapsed condition, and the fish is less plump in consequence. No analyses are given.

† It has been pointed out to the authors that one implication of these results is that the proportion of water associated with protein decreases as the amount of fat increases, from 4·0 to less than 3·0 g. of water per g. of protein over the range studied. [Dr. E. H. Callow has obtained similar results with the lean tissue of beef, for both psoas and mixed muscle.]

TABLE III

Chemical composition of the flesh of British fish

(*a*) *Demersal fish*

Species	Systematic name*	No. of samples	Water per cent.	Fat per cent.	Protein (total N × 6·25) per cent.	Approx. energy value (Calories per lb.)
Cod ..	.. *Gadus morrhua* ..	10–13	80·3–82·6	0·1–0·9	15·0–19·0	310–360
Haddock	.. *Gadus aeglefinus* ..	29–44	79·1–84·1	0·1–0·6	14·6–20·3	280–380
Whiting	.. *Gadus merlangus* ..	2–7	80·4	0·2–0·6	16·4–19·0	330–370
Saithe	.. *Gadus virens* ..	1–8	81·2	0·3–0·6	16·4–20·3	320–400
Pollack	.. *Gadus pollachius* ..	2	—	0·6–0·8	18·1–19·1	360–390
Ling ..	.. *Molva vulgaris* ..	1–3	78·3	0·1–0·4	19·5–22·2	370–430
Torsk	.. *Brosmius brosme* ..	1	—	0·5	18·4	360
Hake ..	.. *Merluccius vulgaris* ..	1–3	79·5	0·4–1·0	17·8–18·6	320–380
Plaice	.. *Pleuronectes platessa*	2–6	80·8	1·1–3·6	15·7–17·8	360–490
Lemon sole	.. *Pleuronectes microcephalus*	1–5	78·9	0·5–3·8	16·4–18·4	330–370
Witch	.. *Pleuronectes cynoglossus*	1–7	81·0	0·2–12·2	14·6–17·5	340–860
Flounder	.. *Pleuronectes flessus* ..	1	81·3	0·3	16·8	330
Megrim	.. *Arnoglossus megastoma*	1–2	80·0	1·0–3·9	17·8	360
Dab ..	.. *Pleuronectes limanda*	1–3	79·1	0·5–1·2	12·8–18·2	260–390
Sole ..	.. *Solea vulgaris* ..	1	77·9	1·8	18·8	430
Brill ..	.. *Rhombus laevis* ..	1	76·0	2·5	19·8	470
Turbot	.. *Rhombus maximus* ..	1–4	78·3	2·1–3·9	16·8–20·6	390–420
Halibut	.. *Hippoglossus vulgaris*	3–4	75·4–79·0	0·5–9·6	18·0–18·8	440–740
Skates and rays	*Raja sp.*	3–7	76·8–82·2	0·1–1·6	18·2–24·2	(400–450)
Dogfish	.. *Acanthias vulgaris* ..	1–4	75·1	3·9–5·6	19·6	(600)
Catfish	.. *Anarrhichas lupus* ..	1–4	78·1	2·1–3·8	17·0–19·7	410–530
Conger eel	.. *Conger vulgaris* ..	1–2	79·6	0·2–11·9	19·1	360
Redfish	.. *Sebastes norvegicus* ..	2	—	3·2–3·8	18·1–18·5	460–520
Gurnards	.. *Trigla sp.*	2–3	76·0–77·2	1·1–2·3	19·7–20·2	410–470
Red mullet	.. *Mullus sp.*	1	74·9	5·1	19·0	570
Grey mullet	.. *Mugil sp.*	1–2	75·6	3·6–3·9	19·5	530
Bass ..	.. *Labrax lupus* ..	1	77·0	2·5	19·3	470
Bream	.. *Sparus centrodontus*†	1	78·8	1·5	17·6	390
John Dory	.. *Zeus faber*	1	78·0	1·3	18·4	400

*Wherever possible the later classification (e.g., that of Day) taken from Jenkins' *The Fishes of the British Isles*,[28] is given unless indicated (†).

(*b*) *Pelagic fish*

Series	No. of determinations	Regression line W = Water per cent. F = Fat per cent. R = Residue per cent. P = Protein per cent. (total N × 6·25)	Correlatation coefficient (*r*)	Probability (P) of significance of *r*	Standard error of regression coefficient (of F)	Probability of significance of regression coefficient	Approx. energy value (Calories per lb.)
		Herring (Clupea harengus)					
Lovern[23]	100*	W = 80·18 − 0·959 F	−0·986	—	—	—	—
		R = 19·82 − 0·041 F	−0·248	—	—	—	—
Lovern and Reay ..	223	W = 80·02 − 0·935 F	−0·979	<·001	±0·013	<·001	—
		R = 19·98 − 0·065 F	−0·317	<·001	±0·013	<·001	334 + 41·4 F
Various[10,14,17,20,26,27]	46	W = 76·66 − 0·740 F	−0·959	<·001	—	—	—
		R = 23·34 − 0·260 F	−0·765	<·001	—	—	—
Bähr[29]	83	W = 80·240 − 0·9426 F	−0·969	<·001	—	·02–·05	—
		R = 19·760 − 0·0574 F	−0·231	·02–·05	—	—	331 + 41·2 F
		P = 18·154 − 0·0566 F	−0·309	<·01	—	·01–·001	338 + 41·1 F
		Sprat (Clupea sprattus)					
Bähr[29]	20	W = 83·39 − 1·022 F	−0·942	<·001	—	—	—
		R = 16·61 + 0·022 F	+0·061	>·1	—	—	278 + 41·8 F
Robertson[30] ..	47	W = 81·51 − 0·971 F	−0·987	<·001	—	—	—
		R = 18·49 − 0·029 F	−0·185	>·1	—	—	308 + 41·6 F

* Results analysed mathematically by Dr. E. H. Callow.

(*c*) *Freshwater fish*[10,11,14,20,21,32]

Species	Systematic name	No. of samples	Water per cent.	Fat per cent.	Protein (total N × 6·25) per cent.	Approx. energy value (Calories per lb.)
Salmon	*Salmo salar*	1–10	66·6	0·35–14 (kelt—fresh run)	21·5	840[25]*
Salmon parr	,, ,,	1	—	3·9	—	—
Salmon smolt	,, ,,	1	—	1·2	—	—
Sea trout	*Salmo trutta*	1–3	—	2·7–10·8	19·1	470
Brown trout	,, ,,	1–2	78·8	1·2–6·9	18·8	400
Perch	*Perca fluviatilis*	1	80·4	0·8	17·6	360
Eel	*Anguilla vulgaris*	1–8	60·0	8·0–31·0 (12 in.–25 in.)	14·4	1310
Carp	*Cyprinus carpio*	2	77·9–78·4	1·3–2·2	18·2–19·1	410–420

* As canned, probably *Onchorhyncus sp*[34].

(*d*) *Shell fish*[10,11,12,34]

Species	Systematic name	No. of samples	Water per cent.	Fat per cent.	Protein (total N × 6·25) per cent.	Approx. energy value (Calories per lb.)
Crustaceans—						
Crab	*Cancer pagurus*	1–3	73·6	0·2–6·6	22·4	450–670
Lobster	*Homarus vulgaris*	2–4	71·5–75·0	0·3–2·5	19·7–20·7	420–440
Prawn	*Leander serratus*	1	71·2	1·3	22·8	480
Shrimp	*Crangon vulgaris*	2	67·6–70·0	0·9	22·0–23·2	450–500
Molluscs—						
Oyster	*Ostrea edulis*	c. 84	76·6–83·1	1·1–2·5	8·6–12·6	320–460
Mussel	*Mytilus edulis*	2–5	84·1–84·4	0·8–2·3	8·9–11·7	270–300
Scallop	*Pecten maximus*	1–2	78·4	0·5–1·0	17·5	350
Whelks	*Buccinum undatum*	1	77·2	0·5	17·5	390
Winkles	*Littorina littorea*	1	72·4	2·1	18·0	510
Cockles	*Cardium edule*	1	54·5	0·4	13·2	390

(*e*) *Fish roe and milt*[10,11,14,20]

Species	M(ale) F(emale) (where stated)	No. of samples	Water per cent.	Fat per cent.	Protein (total N × 6·25) per cent.	Approx. energy value (Calories per lb.)
Cod	—	2–3	70·6–78·7	0·9–2·0	14·7–24·3	350–520
Haddock	—	1	72·5	1·0	21·4	440
Ling	—	1	68·3	3·5	21·5	550
Saithe	M	1	—	3·5	25·4	610
,,	F	4	—	1·7–2·7	11·8–14·2	290–330
Plaice	—	1	63·5	0·3	30·6	580
,,	F	1	—	2·9	34·0	760
Herring	—	2	69·2–76·9	2·4–4·2	17·5–26·3	430–650
,,	M	3	68·6–75·8	2·8–3·6	24·0–26·0	570–640
,,	F	3	62·0–65·1	1·7–3·2	28·1–31·0	610–660
Mackerel	M	1	—	—	17·2	—
,,	F	1	—	—	24·6	—
Lobster	F	1	—	8·0	32·3	940

taken together and correlated. Many results of the earlier workers are partly invalidated by such defects as the occasional use of salt to preserve the fish, the result of which can sometimes be seen in abnormally high figures for ash. Similarly, losses of water by uncontrolled evaporation during transport, drip during thawing, and so on, render other results suspect.

The only other published series of determinations comparable with the work summarized here is that of Bähr.[29] Fish of a wide range of sizes (14·3 cm. to 34·7 cm. and 23·5 g. to 311·4 g.) taken throughout several years from a number of sources varied in fat content from 0·9 per cent. to 17·1 per cent. and in protein content from 15·8 per cent. to 19·8 per cent. (average of 83 values, 17·7 per cent.). The repression line is almost the same as our own; moreover the protein values give almost the same regression coefficient as is obtained with residues. These coefficients, although small, are quite significant, as are ours.

An investigation by the Ministry of Agriculture and Fisheries into the East Anglian sprat fishery[30] showed that the fat content falls steadily throughout the fishing season (October to March), the precise values varying from season to season and from one locality to another, from about 14 per cent. to 17 per cent. in October to 5 per cent. to 7 per cent. in March, falling as low as 1 per cent. in June. The protein contents from 47 analyses vary from 12·8 per cent. to 16·8 per cent. (average 15·4) and the water contents from 65·9 per cent. to 81·6 per cent. In 20 analyses by Bähr[29] from October to April only, fat varied from 5·1 per cent. to 20·5 per cent., protein from 13·6 per cent. to 18·5 per cent. (average 15·7) and water from 60·8 per cent. to 76·5 per cent. The "protein" values are decidedly lower than those obtained by Bähr for herring. The regression lines from Table III*b* are similar to those obtained for herring, although agreement between the two sets of figures is not very good. The beginning of the Norwegian fjord fishery for "brisling" in the spring is governed by the results of laboratory analyses, which show when the average fat content has attained a figure sufficiently high to produce a satisfactory canned article.

U.S. work on the seasonal variation in composition of mackerel[13] has indicated that smaller, i.e., younger, fish show less fluctuation in oil content than larger ones. Also, the curve followed varied little from season to season. Fish from a single sample often varied considerably, e.g., by as much as ± 7 per cent. from the average. The average values of samples rose from 3·9 per cent. (varying from 2·7 per cent. to 7·6 per cent.) in April, at the beginning of the season, to 19·2 per cent. (varying from 10·6 per cent. to 25·6 per cent.) in mid-August, falling again to 8·2 per cent. (varying from 2·2 per cent. to 15·2 per cent.) in mid-November at the end of the season. Energy values likewise varied from about 500 calories per lb. in April through 1100 in August down again to about 600 in November. Bähr,[29] working with fish from European waters, and examining 9 samples in the course of a year, obtained the lowest value of fat-content (1·2 per cent.) in mid-July, and the maximum (10 per cent.) at the end of November, the overall variation in protein and water contents being 18·4 per cent. to 22·9 per cent. and 70·2 per cent. to 78·0 per cent. respectively.

Grey mullet (see Table III*a*) also falls in the pelagic class of fish, and although the few values for the British species, which appears rather irregularly and is unimportant economically, show little variation in fat content, in the common Australian species, *Mugil dobula*, it varies from 1 per cent. to 20 per cent.,[31] and similarly in the U.S. *M. cephalus*.

With the migatory freshwater species also the fat content varies throughout the spawning cycle,[32] but the number of analyses available is insufficient to permit of statistical analysis to determine a relationship similar to that given for herring. In eels, which are always immature since they do not spawn in Europe, there is a clear correlation with the length of the fish,[33] five other values in between the ranges given falling on a straight line when plotted against length. With shell fish analysed raw, the large inedible portion renders them very poor sources of the major food constituents, on a weight basis; thus live oysters contain only 1 per cent. of protein and 0·1 per cent. of fat.[4]

The figures for energy value given in Table III represent the range obtained by calculation from analyses for protein and fat in actual samples, although this range will not always represent the maximum scatter likely to be met with, owing to the small number of samples on which it is sometimes based. Although the energy values, which are subject to the same limitations as the figures for protein, show considerable variation within a species, the extra value of fish in the marine pelagic and freshwater migratory classes is brought out quite clearly. For herring, the formula relating energy value to the fat content of the fish is obtained by substituting the values 4·1 calories per g. and 9·2 calories per g. for protein and fat respectively in the regression expression, allowing for 90 per cent. of the fat-free residue (R) being protein (i.e., about 18 per cent. in the flesh).

Carbohydrates are not given in Table III, since fish is not an important source, although shell fish contain some, notably oysters, where it comprises to 4·1 per cent. to 8·2 per cent. of the meat from various beds. There is evidence of a seasonal fluctuation in the amounts of glycogen and protein present.[12]

Contribution of Fish to the British Diet

Taking 16 per cent. as a fair average value for true protein in fish, the intake per head of the population on the basis of 1938 landings of demersal fish, with an edible portion of 40 per cent., was about 3 g. of protein per day of which 2 g. would be myosin. Pelagic fish, with 55 per cent. edible portion and an average throughout the year of 15 per cent. fat, could have contributed, had it all been consumed in Britain, 1·5 g. each of protein and fat. White fish livers, which amount to about 5 per cent. of the landed weight, when worked up by the commercial steaming process yield about 50 per cent. of oil, and the potential intake of fat from this source could have provided about a further 1 g. per head of the population per day.[35] The small amounts supplied by imported canned salmon, assumed to be 100 per cent. edible and to contain 16 per cent. of protein and 10 per cent. of fat, would have been more than balanced by herrings exported (63 per cent. in 1937). Table IV shows the total quantities available in tons for the year 1938 compared with estimates for the total U.K. consumption of animal and vegetable protein. It is seen that British fish could thus have accounted for only about 10 per cent. of the animal and 5 per cent. of the total protein in our pre-war diet[36,37] and about 2 per cent. of the total fat consumed. These maximal quantities of fat and protein would supply only about 40 calories per day on the average and actually, allowing for imports and exports, the figures would have been nearer 30 calories per day.

TABLE IV

FAT AND PROTEIN IN BRITISH FISH (1938)

Type	Fat	Protein
	(thousands of tons)	
Demersal fish	19* (livers)	49
Pelagic fish†	25	27
	44	76
Imported canned salmon	6	9
Total consumption (animal)	1840[37]	780[37]
Total consumption (animal and vegetable)	2100[37]	1340[36]

* Potential figure ; not all livers are rendered to obtain the oil.

† Potential figure ; almost two-thirds exported.

GLYCOGEN AND LACTIC ACID

Lactic acid is formed by the breakdown of glycogen immediately after death in unexercised vertebrate fishes.[38] After about 15 hours at 15° C., the concentration in haddock has reached about 0·4 per cent. to 0·45 per cent. if sufficient glycogen is present, when further enzyme action is inhibited by the acidity; although the glycogen continues to break down, no more lactic acid is formed.[39] Fish caught by line or trawl struggle violently and may be dead when landed on deck. For fish caught by hand-line, the glycogen content has been found to be as low as 0·01 per cent. in a cod, the average for 15 haddock (*Melanogrammus aeglefinus*) being 0·12 per cent.[40] Trawled fish contain only traces of glycogen. Haddock usually contain about 0·6 per cent. of lactic acid in the wet muscle, although values as low as 0·11 per cent. have also been reported.[38] Samples of skate have been found to contain 0·13 per cent. and 0·46 per cent. of lactic acid.[41] It has been reported that lactic acid does not disappear from haddock's muscle before 12 days at 0° C., but from more recent work it appears that in cod muscle press juice at 0·5° it is oxidized to carbon dioxide in the presence of trimethylamine oxide by bacterial action after about 4 days.[90] About 1 per cent. of lactic acid has been reported in crayfish.[72]

The *p*H of the muscle of all unexercised living or very freshly killed marine or freshwater teleosts yet examined is in the region of 7·0 to 7·3. If exhausted, or in any event within a few hours after death, by the time rigor mortis has set in, the *p*H has usually dropped to between 6·2 and 6·6 in commercially caught fish. This variation is due to several uncontrolled factors, although it seems that within this range flat fish are slightly more acid than "round" fish, and freshwater fish, perch, pike, and trout, somewhat more alkaline. The range is unmistakeably higher than that reported for mammals,[42] and this can be accounted for completely by the smaller amount of lactic acid liberated, together with the higher buffering capacity of fish in that range of *p*H, due to the presence ot trimethylamine oxide.[43] With the onset of staleness, af ter abouf 12 days in ice, the bases formed by bacterial action cause the *p*H to rise, and on retail sale inland most fish is probably slightly on the alkaline side.

The organic phosphates (phosphocreatine, hexose monophosphate, and adenosine triphosphate) are completely broken up a few hours after death to inorganic orthophosphate in amounts estimated on one occasion to be 0·16 per cent. for haddock and 0·11 per cent. for skate (expressed as phosphorus).[41] Published data report inorganic and phosphagen phosphorus respectively for dogfish, 0·051, 0·018; ray, 0·050, 0·040; plaice 0·091, 0·037; cottus, 0·130, 0·013; crab (claw), 0·048, nil; lobster (tail), 0·074, nil; pecten (adductor), 0·114, nil[70]; also, for the common river crayfish (*Astacus fluviatilis*), 0·070 per cent. to 0·127 per cent. of total phosphorus, of which up to 70 per cent. is phosphagen, according to the state of the muscle.[72]

THE PROTEINS OF FISH FLESH

Less is known about the composition of fish proteins than about those of warm-blooded animals. Fish flesh has only a small proportion of connective tissue, this fact, no doubt, accounting for its being so tender. In Table V the value for haddock, already published,[44] is the result of dozens of exhaustive extractions. The values for the other species rest on the alkaline extraction of the muscle of a few individuals, and no great accuracy is claimed for them. Table VI presents the partition of nitrogen between the proteins of haddock muscle.[44]

TABLE V

CONNECTIVE TISSUE OF FISH MUSCLE

Species	Non-soluble stroma (g. N per 100 g. coagulable N)
Haddock	3–5
Cod	5
Hake	4
Plaice	6
Lemon sole	7
Dab	6
Halibut	2
Herring	5
Catfish	7
Monk fish	5
Gurnard	5
Dogfish	11
Skate	6

Bate-Smith has communicated privately the results of a preliminary cataphoretic analysis of cod muscle juice. On dialyzing against distilled water, six fractions were obtained at mobilities of about 0·8, −1·2, −1·8, −2·3, −2·9, and $-5 \cdot 7 \times 10^{-5}$. In the rabbit, the fraction with mobility of −1·2 corresponds with myogen, −2·3 with "globulin X"(not hitherto detected in fish muscle), and −5·7 with myoalbumin. The remaining three mobilities correspond with no known fractions (Table VII).

TABLE VI

ROUGH FRACTIONATION OF THE PROTEINS OF HADDOCK

	g. N per 100 g. total coagulable N		
(*A*) Soluble in 7 per cent. LiCl	85		
(*B*) "Myosin"	67		
(*C*) "Myogen"	18		
(*D*)	Total intracellular		
	Soluble in dilute HCl		Soluble in dilute NaOH
	97		95
	Residual intracellular		
(*E*) Total ($D - A$)	12		10
Acid-soluble	6	Alkali-soluble	9

TABLE VII

CATAPHORETIC FRACTIONATION OF COD MUSCLE PROTEINS (MOBILITIES OF FRACTIONS × 10^{-5})

	Fraction					
Dialysis of juice	1	2	3	4	5	6
A. *against* 0·05M-*buffer* p*H* 7	0·8	(−1·5)		—	—	−5·7
B. *against distilled water*—						
1. *precipitate* taken up in 0·05M-phosphate + 1 per cent. KCl ..	—	—	−1·9	−2·4	—	—
2. *supernatant* (dialyzed against 0·05M-buffer)	0·6	−1·2	−1·6	−2·2	−2·8 (+ pigment)	—
3. *supernatant* after acidification and neutralization to remove bulk of myogens	0·5	−1·1	—	−2·3	−3·0	—
4. *supernatant* acidification repeated ..	1·0	—	—	—	—	—
5. corresponding fractions in rabbit	—	Myogen	—	Globulin X	—	Myoalbumin

The amino-acid composition of fish mucle protein has been studied,[85] but there has been no complete amino-acid analysis of a fractionated protein, although Bailey[16] has published the results given in Table VIII for haddock and lobster myosins, accounting for 10 per cent. of protein present.

The general order of magnitude of these amino-acid constituents is the same as for myosin from warm-blooded animals.

TABLE VIII

ANALYSIS OF MYOSINS OF HADDOCK AND LOBSTER

	(Per cent. of myosin dry weight)	
	Haddock	Lobster
N	16·6	16·6
S	1·21	1·21
Amide N (as per cent. of total N)	(6·66)	(6·75)
Cystine	0·94	0·92
Methionine	3·65	3·45
Tyrosine	4·30	3·58
Trytophan	0·95	0·85
Total accounted for	9·84	8·80

THE NITROGENOUS BASES

These bases, whilst making only a minor contribution to the food value of fish, are said to be of dietetic importance in affecting the secretion of the digestive juices[45b and c]; as will be shown later, the nature of the bases present may, in fact, determine whether the fish is edible or not. The bases may be divided into the following groups: the volatile bases (ammonia, mono-, di-, and tri-methylamines); trimethylammonium bases (trimethylamine oxide and betaines); guanidine derivatives (creatine, methylguanidine, etc.); glyoxaline derivatives (carnosine, anserine, and histidine); and urea. In addition to these groups, certain purine derivatives are known to be present in some species of fish[46]; since little precise information is available about the commoner varieties, these have been excluded from the present discussion.

There have been published one or two results on Canadian fish and crustacea,[45 b and c] but so far no complete quantitative analyses of British or European species, even of our commoner marine types. Figures for individual components of the above groups do exist, however, and from all the data available the following generalizations may be made.

(1) The total non-protein nitrogen in fish and crustacean muscle is somewhat higher than in mammals,[42] being higher in the elasmobranchs and crustacea than in the teleosts (see Table IX).

(2) In the elasmobranchs about 80 per cent. of the non-protein nitrogen occurs as urea (45 per cent.), trimethylamine oxide (25 per cent.), and creatine (7 per cent. to 9 per cent.), whilst in the teleosts about 65 per cent. of the non-protein nitrogen can be accounted for by trimethylamine oxide (30 per cent.) and creatine (35 per cent.). In freshwater fish, as in mammalian muscle, the creatine and purine fractions appear to be the most important.

These figures apply, of course, only to newly-caught fish, since both urea and trimethylamine oxide are easily reduced by bacteria to ammonia and trimethylamine respectively. For this reason some of the recorded figures for total volatile bases, urea, and trimethylamine are of limited value, since no indication has been given of the freshness of the fish; some have obviously been quite stale.[47]

Trimethylammonium Bases

Trimethylamine oxide.—Much work has been done recently on this important source of the non-protein nitrogen. In Table X is given a summary of most of the reliable data on the distribution of trimethylamine oxide in the fresh muscle of the commoner edible marine and freshwater fish and crustacea. For comparative purposes the data of Cook[48] and Beatty,[49] for the cognate Canadian species, have also been included.

The trimethylamine oxide content increases sharply from freshwater fish to marine teleosts, and from them to the marine elasmobranchs, although figures higher for teleosts than elasmobranchs are said to occur.[50] Trimethylamine oxide is seen to be characteristic of marine species, including the crustacea, rather than of freshwater

TABLE IX

TOTAL NITROGEN (CRUDE PROTEIN), NON-COAGULABLE NITROGEN (TRUE PROTEIN) AND NON-PROTEIN NITROGEN IN FISH AND CRUSTACEAN MUSCLE

Species	Author	No. of samples	Total nitrogen						Coagulable nitrogen						Non-protein Nitrogen as per cent N		
			as per cent. N			Protein N × 6·25			as per cent. N			N × 6·25					
			Min.	Max.	Aver.	Min.	Max.	Aver.	Min.	Max.	Aver.	Min.	Max.	Aver.	Min.	Max.	Aver.
Haddock	Reay[88]	15–24	2·56	3·02	2·85	16·0	18·9	17·8	2·14	2·83	2·48	13·4	17·7	15·5	—	—	0·37*
,,	Komarov[45b]	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·38
,,	Campbell[45c]	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·42
Cod	Reay[88]	1	—	—	2·83	—	—	17·7	—	—	2·47	—	—	15·4	—	—	0·36*
,,	Campbell[45c]	2	—	—	—	—	—	—	—	—	—	—	—	—	0·40	0·42	0·41
Whiting	Reay[88]	4	—	—	—	—	—	—	2·69	2·75	2·70	16·8	17·2	16·9	—	—	—
,,	Boury[89]	2–3	2·81	2·86	2·84	17·6	17·9	17·7	2·45	2·48	2·47*	15·3	15·5	15·4	0·34	0·38	0·36
Hake	Reay[88]	1	—	—	—	—	—	—	—	—	2·85	—	—	17·8	—	—	—
Plaice	Reay[88]	1	—	—	—	—	—	—	—	—	2·88	—	—	18·0	—	—	—
Lemon sole	Reay[88]	2	—	—	—	—	—	—	2·46	3·00	2·74	15·4	18·8	17·1	—	—	—
Dab	Reay[88]	1	—	—	—	—	—	—	—	—	2·88	—	—	18·0	—	—	—
,,	Boury[89]	2	2·93	3·80	3·37	18·3	23·7	21·1	2·42	2·69	2·56*	15·1	16·8	16·0	—	—	—
Halibut	Reay[88]	1	—	—	—	—	—	—	—	—	3·00	—	—	18·8	—	—	—
,,	Cook[48]	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·33
Dogfish	Reay[88]	2	—	—	—	—	—	—	1·98	2·40	2·19	12·4	15·0	13·7	—	—	—
Skate and Rays	Reay[88]	2	—	—	—	—	—	—	2·61	2·67	2·64	16·3	16·7	16·5	—	—	—
,, ,,	Campbell[45c]	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1·42
,, ,,	Boury[89]	1	—	—	4·03	—	—	25·2	—	—	2·61*	—	—	16·3	—	—	1·42
Gurnard	Reay[88]	—	—	—	—	—	—	—	—	—	2·78	—	—	17·4	—	—	—
Catfish	Reay[88]	—	—	—	—	—	—	—	—	—	2·33	—	—	14·6	—	—	—
Angler	Reay[88]	—	—	—	—	—	—	—	—	—	2·05	—	—	12·8	—	—	—
Herring	Boury[89]	4	2·70	3·01	2·90	16·9	18·8	18·1	2·36	2·63	2·53*	14·7	16·4	15·8	0·34	0·40	0·38
Sardine	Boury[89]	3	3·27	3·78	3·46	20·4	23·6	21·6	2·83	3·19	2·97*	17·7	19·9	18·6	0·44	0·59	0·49
Mackerel	Boury[89]	7	2·90	3·10	3·05	18·1	19·4	19·1	2·39	2·76	2·60*	14·9	17·2	16·2	0·38	0·51	0·45
Dorado (dolphin)	Boury[89]	1	—	—	3·22	—	—	20·13	—	—	2·83	—	—	—	—	—	0·37
Salmon	Campbell[45c]	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·47
Lobster	Campbell[45c]	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·68
,,	Cook[48]	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0·62

* By difference.

TABLE X

THE DISTRIBUTION OF TRIMETHYLAMINE OXIDE IN AQUATIC ANIMALS (EXPRESSED AS MG. PER 100 G. OF MUSCLE)

Species	Reay[81]	Cook[48]*	Beatty[49] (in the muscle juice)*‡	Lintzel, Pfeiffer and Zippel[52]		Hoppe-Seyler[79]
				July-Aug.	Nov.-Jan.	
Marine elasmobranchs—						
Blue skate (*Raja batis*)	1100	—	—	—		—
Barndore skate (*Raja laevis*)	—	—	1250	—		—
Dogfish (*Nurse hound*) (*Scyllium canicula*)	1430	—	—	—		—
,, (*Acanthias vulgaris*)	—	—	1430	—		—
Spotted dogfish (*Pristiurus melanostomus*)†	1080	—	—	—		—
Marine teleosts—						
Haddock (*Gadus aeglefinus*)	220–300	—	—	—		—
,, (*Melanogrammus aeglefinus*)	—	390	380	—		—
Codling (*Gadus morrhua*)	360–400	—	—	—		—
Cod (*Gadus morrhua*)	—	460	670	—		—
Whiting (*Gadus merlangus*)	236	—	—	—		—
Pollack (*Pollachius virens*)	—	190	480	—		—
Hake (*Urophycis sp.*)	—	—	890	—		—
Lemon sole (*Pleuronectes microcephalus*)	190	—	—	—		—
Halibut (*Hippoglossus vulgaris*)	—	270	—	—		—
John Dory (*Zeus faber*)	358	—	—	—		—
Herring (*Clupea harengus*)	313	—	480	—		—
Mackerel (*Scomber scombrus*)	—	—	260	—		—
Marine crustacea—						
Lobster (*Homarus vulgaris*)	—	154	—	—		325
Norway lobster (*Nephrops norvegicus*)	653	—	—	—		—
Freshwater fish—						
Eel (*Anguilla vulgaris*)	—	—	—	36·9	—	—
Pike (*Esox lucius*)	14	—	—	23·7	30·3	—
Perch (*Perca fluviatilis*)	0	—	—	53·1	—	—
Trout (*Salmo trutta*)	9	—	—	—	—	—
,, (*Salmo fario*)	—	—	—	73·1	—	—
Tench (*Tinca vulgaris*)	—	—	—	24·9	—	—
Bream (*Abranis vimba*)	—	—	—	92·3	{22·9 4·7}	—
Rudd (*Leuciscus erythrophthalmus*)	—	—	—	56·5	5·36	—
Chub (*Leuciscus cephalus*)	—	—	—	22·4	40·1	—
Freshwater crustacea—						
Crayfish (tail muscle) (*Astacus fluviatilis*) (?)	—	—	—	{13·3 23·9}	—	50

* Canadian caught fish. † See footnote to Table III*a*. ‡ Probably 20 per cent. higher than in the muscle.

species. No quantitative data are available as to the effect of age, sex or season of the year on the trimethylamine oxide content of sea fish, although Hoppe-Seyler and Schmidt[51] found no support for the assumption that the spawning period or season of the year was responsible for the accumulation of the base. Lintzel's[52] figures for freshwater fish suggest, however, that this point requires further investigation.

Unlike urea, trimethylamine oxide was known as a synthetic chemical entity some 13 years[53] before being isolated, by Suwa, from dogfish muscle.[54] Along with urea, it is considered to play an important part in the osmotic regulation of fishes,[55] and it is thought that it may arise from the methylation and oxidation of the lowest cleavage products of proteins, probably ammonia.[46]

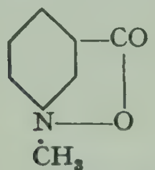
Amongst the interesting properties of trimethylamine oxide the following may be mentioned. It acts as a weak base, its salts having marked buffer action in the region of *p*H 4·5 ; it can act as a hydrogen acceptor, being reduced, for example, either by glutathione in the muscle system,[56] or by bacteria[57] (Achromobacter, Micrococci, etc.), to trimethylamine. This bacterial reduction seems to be the explanation of the proposed objective method of estimating the freshness of fish by the direct titration of the muscle with acid, under standardized conditions.[58]

In the presence of catalysts or by heating to a high temperature,[53] trimethylamine oxide is broken down to dimethylamine and formaldehyde. As a result, canned[59] and other marine products[60] frequently have a much higher formaldehyde content than fresh fish.

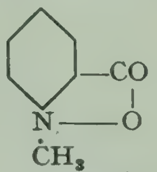
It has been claimed that, along with betaine and other trimethylated compounds, it is responsible for the production of fishy flavours in various foodstuffs, e.g., milk and butter.[61] In every instance of fishiness, a fat is present along with trimethylamine or its oxide, or compounds which can give rise to them (choline, lecithin, etc.), and it has been suggested that the trimethylamine, owing to its ease of oxidation, takes part in reactions involving the transfer of nitrogen into organic combination with the fat breakdown products, to form fat-soluble "fishy" flavoured products.

Before leaving trimethylamine oxide, brief mention may be made of the other trimethylammonium bases (the betaines), which occur in small quantities in some fish and crustacea. Thus, glycine betaine (75 mg. per 100 g. of muscle) has been found in the witch (*Pleuronectes cynoglossus*),[51] in dogfish[62] (0·7 per cent. in adults, 1·2 per cent. in embryo), in rays[63] and sharks[63] (0·21 per cent. to 0·26 per cent.), in cod[63] (0·102 per cent.), in carp[63] and pike[52]

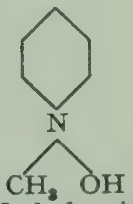
(0·010 per cent. to 0·014 per cent.), whilst γ-butyrobetaine has been found in the eel[64] (0·01 per cent.). From the crustacea, e.g., the lobster, homarine, an isomeride of trigonelline, has been isolated,[65] whilst in both crustacea and molluscs the closely related N-methylpyridine has been found.[66] This last compound could arise from either trigonelline or homarine by decarboxylation. Trigonelline, it is interesting to note, occurs normally in the urine[86] or is produced by feeding nicotinic acid; the relationship of these compounds to one another will be seen from their formulae.



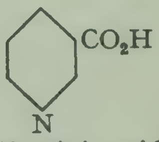
Trigonelline



Homarine



N-Methylpyridine



Nicotinic acid

It might be added that the ingestion of trimethylamine oxide, as of some of the betaines, results in its excretion, unchanged, in the urine. Trimethylamine, on the other hand, is oxidized in the body and is excreted almost wholly as trimethylamine oxide.[67]

Guanidine Derivatives

Creatine.—The data available on creatine apply mainly to Canadian[45] and American[68] species, although from the work of Mellanby,[69] Eggleton and Eggleton,[70] and Bate-Smith[41] some figures are available for British caught fish. In general, it has been found that the creatine content of the skeletal muscle of fish varies considerably, not only in the different species, but also between different individuals of the same species. In distinction to urea and trimethylamine oxide, there appears to be no systematic difference between teleosts and elasmobranchs, but, in general, the muscle of fish contains more creatine than that of mammals. Thus, from 16 species of fish, including elasmobranchs and teleosts, an average value of 0·480 per cent. of creatine was found, compared with 0·424 per cent. in mammals.[41] In the crustacea (lobster,[70], crabs,[70] and crayfish[71]) and shellfish (mussel, etc.[70]) only traces have been found, it being claimed that in the crustacea arginine replaces creatine in the combination with phosphorus[72] (Table XI). In addition to creatine, methylguanidine occurs in fair amount in sharks (dogfish?), skate, and cod and as traces in carp.[63]

Glyoxaline Derivatives

Anserine and carnosine.—Some qualitative results on the distribution of anserine and carnosine have been recorded, but accurate

TABLE XI

DISTRIBUTION OF CREATINE IN THE MUSCLE OF FISH AND CRUSTACEA EXPRESSED EITHER AS PER CENT. CREATINE OR AS PER CENT. NITROGEN ON THE WET MUSCLE

Common name	Systematic name	Author	European creatine per cent.	Canadian and American creatine per cent.
Elasmobranchs—				
Shark	*Sphyrna zygaena*†	Kisch[82]	0·401	—
Dogfish	*Squalus sucklii*†	Hunter[68]	—	0·600
,,	*Acanthias vulgaris*	Eggleton and Eggleton[70]	0·460	—
Skate	—	Mellanby[69]	0·280	—
,,		Bate-Smith[41]	0·339*	—
,,	*Raja clavata*	Eggleton and Eggleton[70]	0·440	—
,,	*Raja stabuliformis*	Campbell[45c]	—	0·337
,,	*Raja binoculata*	Hunter[68]	—	0·481
Ray	*Torpedo ocellata*	Kisch[82]	0·287	—
Teleosts—				
Cod	*Gadus morrhua*	Mellanby[69]	0·350	—
,,	,, ,,	Campbell[45c]	—	0·576
Haddock	*Gadus aeglefinus*	Bate-Smith[41]	0·478*	—
,,	*Melanogrammus aeglefinus*	Campbell[45c]	—	0·639
Herring	*Clupea harengus*	Campbell[45c]	—	0·577
,,	*Clupea pallasii*	Hunter[68]	—	0·740
Salmon	*Salmo salar*	Campbell[45c]	—	0·602
,,	*Oncorhynchus tschawytscha*	Okuda[68]	—	0·618
Sea wrasse	*Labrus turdus*†	Kisch[82]	0·443	—
Crustacea—				
Lobster	*Homarus americanus*	Campbell[45c]	—	0·005
,,	*Homarus vulgaris*	Eggleton and Eggleton[70]	0	—
Crab	—	Meyerhof[72]	arginine instead	—
Freshwater fish—				
Burbot	*Lota vulgaris*	Palladin and Wollenberger[83]	0·526	—
Carp	*Cyprinus carpio*	Okuda[68]	—	0·487
,,	,, ,,	Palladin and Sigalova[84]	0·350–0·460	—
Crayfish	(*Astacus fluviatilis*) (?)	Kutscher[71]	arginine instead	—
Shellfish—				
Mussel	*Mytilis* (adductor muscle)	Eggleton and Eggleton[70]	0	—
Mollusc	*Pecten*	Eggleton and Eggleton[70]	0	—

* Muscle juice. † See footnote to Table III*a*.

quantitative data are lacking, more particularly in view of the recent criticism of Clifford's carnosine results (determination by diazo-method[73]) by Ackermann and Hoppe-Seyler.[74] As a result of their work, it appears to be established (by the direct isolation and analyses of the characteristic salts) that anserine occurs in considerable amounts, carnosine only in traces, in marine elasmobranchs (e.g., herring shark); in the cod and conger eel carnosine is completely replaced by anserine, whilst in the freshwater eel only carnosine is present. In herring and perch, neither carnosine nor anserine is present. The results of Clifford and Ackermann are given in Table XII.

TABLE XII

DISTRIBUTION OF ANSERINE AND CARNOSINE IN FISH

(AFTER CLIFFORD[73] AND ACKERMANN AND HOPPE-SEYLER[74])

Fish species	Carnosine (?) Clifford	Ackermann and Hoppe-Seyler		
		Clifford's diazo-reaction	Anserine (direct isolation, etc.)	Carnosine (direct isolation, etc.)
Herring shark ..	—	+ve	+ve	−ve
Cod	−ve	−ve	0·30 per cent.	−ve
Haddock ..	−ve	—	—	—
Hake	−ve	—	—	—
Halibut	−ve	—	—	—
Plaice	−ve	—	—	—
Sole	−ve	—	—	—
Herring	0·16 per cent.	+ve	−ve	−ve
Sprat	0·47 ,,	—	—	—
Mackerel ..	0·57 ,,	—	—	—
Mullet (grey) ..	0·18 ,,	—	—	—
,, (red) ..	0·16 ,,	—	—	—
Sea bream ..	0·14 ,,	—	—	—
Pike	+ve	—	—	—
Salmon	+ve	—	—	0·055 per cent.[87]
Trout	+ve	—	—	—
Eel	0·37 per cent.	+ve	−ve	0·066 per cent.[87]
Conger eel ..	—	−ve	0·04 per cent.	−ve
Perch	+ve	+ve	−ve	−ve
Tunny	—	—	—	0·20 per cent.[87]
Lobster ..	—	—	−ve	−ve[70]
Scallop	—	—	−ve	−ve[70,71]

Histidine.—The presence of histidine in the muscle of various members of the Scombridae has been recorded from time to time,[75] and the recent isolation from mackerel and tunny as the additive compound with barium nitrate has confirmed this.[76] Apart from a value for fresh tunny (0·47[79]) no quantitative data have been recorded. During spoilage, the histidine is converted to histamine and this compound is said to be the pungent principle present in spoiling mackerel.[75]

Urea

Urea exists in considerable quantities in the elasmobranchs (1·82 per cent. to 2·16 per cent. in dogfish muscle,[77] 1·50 per cent. to 1·96 per cent. in rays[78,45c]), in much smaller amounts in the teleosts

(0·003 per cent. to 0·005 per cent. in haddock, cod, herring, and salmon[45c]), and only in traces in the crustacea (lobster [45c, 79]), but, though there are various analyses of the blood and urine of various species of fish, few quantitative data for muscle have been published.[55]

The Volatile Bases

It has already been mentioned that in newly-caught fish, more particularly in the marine species, trimethylamine oxide and urea constitute important fractions of the non-protein nitrogen, and that these two compounds are quickly reduced by bacteria to ammonia and trimethylamine. Hence, during the subsequent storage of fish, the volatile bases soon assume a position of major importance.

In Table XIII are set out the analyses for the volatile bases of some typical species of fish during storage in ice, viz., dogfish, haddock, and perch. Herring and mackerel, stored without ice, are also included, since this is the normal method of handling these fish. Where possible, figures for trimethylamine oxide have also been given.

The table shows that in every species of newly-caught fish, the volatile basic fraction consists almost entirely of ammonia, along with small quantities of dimethylamine and trimethylamine. Further, it will be noted that, although the total of volatile bases increases with increasing length of storage in all the types of fish investigated, the nature of the bases produced depends on the duration of storage and on the species. Thus, in haddock stored in ice there is some increase in dimethylamine up to about the seventh day, with little change in the amounts of the other bases. From the 7th to 11th day the increase in dimethylamine is maintained, but then the tertiary amine begins to rise sharply. From the 11th to the 15th day the production of secondary amine is slowed down, whilst the increase in the tertiary amine is maintained and ammonia begins to increase rapidly. From the 15th day onwards, by which time the fish are becoming unpalatable, the production of tertiary amine is slowed down, whilst increase in ammonia is accelerated (up to the 23rd or 25th day, when it also slows down). During the period of storage the trimethylamine oxide gradually disappears, being changed to trimethylamine. In the freshwater fish, on the other hand, little change occurs until between the 11th and 15th day, when, as in haddock, ammonia begins to be produced, probably from the active decomposition of the protein. However, even at the end of the period of storage (27 days) the total volatile base fraction in

TABLE XIII

THE VOLATILE BASES AND TRIMETHYLAMINE OXIDE IN THE MUSCLE OF VARIOUS SPECIES OF FISH DURING STORAGE IN ICE
NITROGEN (MG.-PER CENT.) IN WET MUSCLE

	0–7 days					7–11 days					
Species	Total volatile bases	Ammonia	Di-methyl-amine	Di-methyl-amine	Tri-methyl-amine bases	Total volatile bases	Ammonia	Di-methyl-amine	Tri-methyl-amine	Tri-methyl-amine oxide	
Dogfish	8·6–8·5	6·0–8·0	0·07–0·07	0·5–1·0	201–190	8·5–12·0	8·0–10·0	0·07–0·07	1·0–1·2	190–170	25 days in ice
Haddock	11·3–11·0	10·0–8·0	0·08–0·06	0·56–1·5	46–61	11·0–19·5	8·0–10·5	0·06–0·14	1·5–6·5	41–29·5	30 days in ice
Perch..	14·36–10·0	12·57–8·5	very slight	0·25–very slight	very slight	10·0–9·5	8·5–10·0	very slight	very slight	very slight	25 days in ice
Herring (May—Fraserburgh, 4 per cent. fat)	10 hrs. in ice*					10–28 hrs. in ice					
	18·6	16·72†	0·08	1·8	58·4	18·6–17·6	16·72–15·4	0·08–0·60	1·8–1·6	—	
	10 hrs. without ice‡					10–28 hrs. without ice					
	18·4	17·0	0·16	1·2	—	18·4–22·4	17·0–20·3	0·16–0·50	1·2–1·6	—	
Herring (July—Fraserburgh, 27 per cent. fat)	12 hrs. in ice*					29–53 hrs. in ice					
	17·0	16·75	0·05	0·20	—	17·0–16·4	16·36–16·0	0·04–very slight	0·60–0·40	—	
	12 hrs. without ice§					29–53 hrs. without ice					
	20·4	19·8	0·17	0·40	—	26·6–50·0	22·49–25·72	0·11–0·28	4·0–25·0	—	
	10 hrs. after catching at 0° C.										
Mackerel	19·8	19·85	0·25	0·20	—						

TABLE XIII—*Continued*

THE VOLATILE BASES AND TRIMETHYLAMINE OXIDE IN THE MUSCLE OF VARIOUS SPECIES OF FISH DURING STORAGE IN ICE NITROGEN (MG.-PER CENT.) IN WET MUSCLE

Species	11–15 days					15–25 or 30 days					
	Total volatile bases	Ammonia	Di-methyl-amine	Tri-methyl-amine	Tri-methyl-amine oxide	Total volatile bases	Ammonia	Di-methyl-amine	Tri-methyl-amine	Tri-methyl-amine oxide	
Dogfish	12·0–45·0	10·0–39·5	0·07–0·07	1·2–6·0	170–145	45·0–165·0	39·5–145·0	0·07–0·07	6·0–26·0	145–65	25 days in ice
Haddock	19·5–34·5	10·5–15·5	0·14–0·17	6·5–11·5	29·5–19·0	34·5–78·0	15·5–49·0	0·17–0·16	11·5–24·0	19·0–0	30 days in ice
Perch	9·5–16·0	10·0–15·5	very slight	very slight	very slight	16·0–80·0	15·5–80·0	very slight	very slight	very slight	25 days in ice
Herring (May—Fraserburgh, 4 per cent. fat)	52–76 hrs. in ice					124–172 hrs. in ice					
	17·8–16·6	16·6–15·2	0·60–0·80	0·60–0·60	—	17·8–17·6	15·46–14·93	0·94–1·07	1·4–1·6	—	
	52–76 hrs. without ice					124 hrs. without ice					
	31·6–41·6	21·9–22·23	1·10–1·67	8·6–17·6	—	119·0	52·7	2·65	63·6	—	
Herring (July—Fraserburgh, 27 per cent. fat)	77–100 hrs. in ice					125 hrs. in ice					
	14·8–16·0	14·2–15·4	very slight	0·6–0·6	—	19·4	17·2	very slight	2·0	—	
	77 hrs. without ice										
	96·0	42·92	0·28	52·8							
Mackerel											

* Iced directly taken from the net. † In all the herring figures, ammonia is estimated by difference.

‡ Temperature of storage 7–11° C. (44·6–52° F.). § Temperature of storage 15·6° C. (60° F.).

For convenience of reference, we give in Table XIV a summary of the figures shown in more detail in Table III.

TABLE XIV

Approximate average composition and yield of filleted fish

	Per cent. edible portion	Water	Composition per 100 g.			Cals.
(a) *Demersal marine fish*			Protein	Fat	Carbo-hydrated	
Gadoids—						
Cod, haddock, saithe, whiting	45	81	16	0·5	0	69
Ling, tusk	50					
Pollack	60					
Hake	65	78	16	3	0	91
Flatfish—						
Flounders	40	79	16	2	0	82
Plaice	45					
Lemon soles, megrims*, dabs, soles, turbot, brill	50					
Witches						
Halibut	60	76	16	5	0	109
Elasmobranchs—						
Skates and rays	45	80	16	1	0	73
Dogfish		78	13	5	0	97
Miscellaneous—						
Monkfish	25	82	13	0·5	0	61
John Dory	40	80	16	1	0	73
Catfish	40	78	16	3	0	91
Gurnards and latchets, bream						
Redfish, red mullet	50	76	16	5	0	109
Congers						
(b) *Pelagic marine fish*						
Herring, pilchards*† ..	55	66	16	15	0	199
Sprats		72	15	10	0	150
Grey mullet		78	16	3	0	91
Mackerel	50	73	16	8	0	136
Smelts						
White bait	100	78	16	3	0	91
(c) *Freshwater fish*						
Salmon	65	67	17	14	0	194
Eels*	50	69	13	16	0	196
(d) *Shellfish*						
Crustaceans—						
Crabs	40	73	20	4	—	116
Shrimps and prawns ..	45	69	21	2	1	106
Lobsters, Norway lobsters,*† crawfish*†		73	20	4	2	124
Molluscs—						
Oysters	10	78	10	2	6	82
Cockles*	20	60	11	0·5	6	73
Periwinkles		74	15	1	5	89
Scallops = clams		78	18	1	—	81
Mussels	30	82	12	2	2	74
Whelks	40	76	18	2	2	98

* Signifies no known edible portion data. † Signifies no known analyses.

perch consists almost entirely of ammonia. Trimethylamine oxide, it will be noted, is absent even in the newly-caught fish.

In dogfish, the amount of tertiary amine produced on storage is similar to that in haddock, although the amount of trimethylamine oxide initially present is much higher than in haddock. On the other hand, the values for the secondary amine are lower than in haddock and show little change during storage. Ammonia, however, begins to increase earlier and reaches higher values than in haddock, probably owing to the breakdown of urea.

Except for a somewhat higher production of ammonia, herrings stored in ice behave very much like haddock; the figures for dimethylamine and trimethylamine in the fatty July fish are, however, decidedly lower than those for the lean May herrings, at least over a period of 5 days. In the fish without ice the whole process is, of course, much speeded up.

The general picture of the results given is, then, that the nature and quantity of the volatile bases present in fish stored in ice depend on the species and on the duration of storage. Normally, the great bulk of the fish landed in this country has been some 11 to 15 days in ice, and in such fish (both teleosts and elasmobranchs) the non-protein nitrogen would consist almost entirely of ammonia and trimethylamine, with small quantities of dimethylamine and trimethylamine oxide.

Finally, it may be stated that the chemical changes described above can be correlated fairly closely with the organoleptic data, and some attempts have been made to use the estimation of dimethylamine and trimethylamine as objective measurements for the degree of freshness in fish.[80]

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CHAPTER XXIV

THE VITAMIN AND MINERAL CONTENTS OF FISH

By J. A. Lovern

In this paper it is proposed to consider fish and their products as sources of vitamins and minerals. As far as possible, the tabular matter is limited to British species, but in a few instances gives American results obtained on closely related forms, usually belonging to the same genus as the corresponding British variety. All the results relate to the edible portion only.

VITAMIN A

Fish furnish the richest natural sources of vitamin A, generally in the form of their liver oils. Like mammals, most fish store the bulk of their reserve vitamin A in the liver, but these reserves are proportionally far larger than those of mammals. Table I gives a selection of the data for fish liver oils; it can be seen how great is the variation in potency, not only from species to species, but even from sample to sample within a particular species. In spite of these variations, however, certain trends are obvious. The smaller gadoid fish, such as haddock and whiting, yield liver oils much poorer in vitamin A than cod-liver oil. The larger gadoids, such as hake and ling, closely resemble cod. Some other species, such as halibut and tunny, contain relatively enormous amounts of vitamin A in their

TABLE I

VITAMIN A IN FISH LIVER OILS

Species	Oil in liver (per cent.)*	I.U. per g.	Suggested average†
Haddock	50–75	102[1]	100
Whiting	50–75	128[1]	100
Cod	50–75	400–4000[1]; 1000[2]	1000
Ling	50–75	384[1]	1000
Hake	50–75	1024[1]	1000
Dogfish	50–75	1500[2]	—
Halibut	15–20	2816–360,000[1]; 50,000[2]	50,000
Tunny	15–20	36,000–84,000[1]; 10,000[2] 140,000[7]	5000
Herring	10	3630–10,272[1]; 10,000[2]	5000
Salmon	10	256–7680[1]; 10,000[2]	5000

* Average values, subject to large seasonal variations.

† Based largely on the author's experience.

livers and yield highly potent oils. Fish with fatty muscle tissue (e.g., herring and salmon) do not have more than a few per cent. of oil in their livers, and in consequence yield liver oils of high potency. The total vitamin A in the livers of such fish is usually not disproportionately high compared with the gadoids, which have large livers containing 50 per cent. to 75 per cent. of oil.

TABLE II

VITAMIN A IN FISH FLESH

Species	I.U. per 100 g.
White fish (i.e., cod, haddock, etc.)	50[2]
Herring	200[2] ; 20–380[3] ; 35–240[4]
Mackerel	150[2]
Brisling (sprats) (as canned)	100–1000[3]
Salmon (Pacific)*	440–5250[1]
,, (Atlantic)	Nil[5,8]
Eel, freshwater	Up to 4500[5]

* Assuming 10 per cent. of oil in the flesh.

Table II gives a summary of such few results as have been reported for the vitamin A content of fish flesh. I have ignored results for whole fish when it is not clear if viscera were removed, but have included brisling as canned, as this is the form in which they are mainly consumed. It will be seen that fatty fish are appreciably richer in vitamin A than are white (lean) fish, but are not valuable sources of this substance. (I should regard the higher value for Pacific salmon with suspicion.) On the whole, an average value for fatty fish other than eels may be taken at about 200 I.U. per 100 g. For eels, the content increases with the size of the fish, the value recorded being for moderately large specimens. These fish appear to be outstanding in having a high vitamin A content of the flesh. In general, processing of fish appears to leave the vitamin A almost intact. Lunde[3] reported that when fish were smoked whole, as with brisling (sprats) and sild (small herring), there was no loss of vitamin A, but when smoked as fillets (kippers) there was a slight loss. Brisling and sild canned in olive oil lost no vitamin A even after storage for 4 years, but there was a loss, greater than that during smoking, when kipper fillets were canned in the dry condition. The final canned kippers contained 50 I.U. per 100 g. to 60 I.U. as against 20 I.U. to 380 I.U. for fillets from similar fresh fish. In a later paper[2] Lunde claimed that a long series of tests showed that vitamin A in fish flesh is stable to canning.

VITAMIN D

Table III shows a selection of the data available for the vitamin D content of fish liver oils. Presumably gadoid fish other than cod closely resemble the latter, although experimental values are lacking. Halibut and, especially, tunny are again outstandingly good. The non-fatty livers show the same high concentrations of vitamin D in the liver oils as they do of vitamin A. Dogfish, like all elasmobranchs, is almost devoid of vitamin D. In Table IV is given the vitamin D of fish flesh. White fish are reported as entirely lacking in this substance, whilst fatty fish contain appreciable amounts.

TABLE III

VITAMIN D IN FISH LIVER OILS

Species	Oil in liver (per cent.)*	I.U. per g.
Cod	50–75	60–300[1]
Halibut	15–20	200–4000[1]
Tunny	15–20	33,000–57,000[1]; 30,000[2,7]
Mackerel	10	800[2]
Salmon	10	1000[2]
Dogfish	50–75	3[1]; 35[2]

* Average values, subject to large seasonal variations.

TABLE IV

VITAMIN D IN FISH FLESH

Species	I.U. per 100 g.
White fish (i.e., cod, haddock, etc.)	Nil[2]
Herring	1202[2]; 300–1700[4]
Mackerel	700[2]
Salmon (canned)	200–800[1]; 600[8]
Eel, freshwater (Australian)	4700[6]

The freshwater eel, of the same genus as our own European species, is unusually rich in vitamin D. According to Lunder[2,3] vitamin D in fish flesh is completely stable to smoking, canning or salting, and to storage of the canned article for several years. On the other hand, the data of Bacharach *et al.*[4] suggest a considerable loss of vitamin D when herring are canned, but their experiments were not claimed as conclusive. It will have been noticed that vitamins A and D show a rough similar distribution over many species of fish, although there are quantitative differences. White fish flesh is a very poor source of both, whilst fatty fish flesh is a fairly good source. Amongst the fatty fish the flesh of the freshwater eel is outstandingly rich in both vitamins. For liver oils the gadoids (cod, haddock, etc.) fall at the lower end of the scale for both vitamins (apart from the elasmobranchs—sharks and skates—which contain only traces of vitamin D), fatty fish with small non-fatty livers, such as herring, mackerel and salmon are intermediate, and a few other species, exemplified by halibut and tunny, are outstandingly rich in both vitamins.

VITAMIN B_1

Table V shows the content of vitamin B_1 in fish flesh, a relatively poor source of the same order as beef. Fish roe, however, is an exceedingly good source, as can be seen from Table VI, and compares favourably with yeast. Fish milt (soft roe) is intermediate between flesh and roe. The herring, as also the brisling,[2] is an exceptionally poor source of vitamin B_1 and even the roe is poor. Lunde[2] states that herring liver also contains too little vitamin B_1 for accurate estimation, whilst the livers of gadoids contain 50 I.U. per 100 g. to 100 I.U. per 100 g. The results of Pyke and Wright[8] for salmon flesh suggest a considerable loss of vitamin B_1 on canning, although only one uncanned (chilled) specimen was tested. Lunde[2] claims that when fish roe is canned, 80 per cent. of the vitamin B_1 remains intact, a considerable proportion of it, however, passing into the free liquor in the can.

TABLE V

VITAMIN B_1 IN FISH FLESH

Species	I.U. per 100 g.
Cod	20[2]; 40[9]
Haddock	20[1]
Whiting	30[9]
Plaice	35[2]
Herring	8–20[1]; 10[2]
Salmon (chilled)	80[8]
,, (canned)	8–15[8]

TABLE VI

VITAMIN B_1 IN FISH ROE AND MILT

Material	I.U. per 100 g.
Cod roe	300–600[1]
,, milt	55–70[1]
Haddock roe	250–730[1]
Mackerel roe	200[2]
Herring roe	10[2]
,, milt	12[2]; 60[9]

RIBOFLAVIN

The riboflavin content of the flesh of a representative list of species is given in Table VII, and of roes and milts in Table VIII.

TABLE VII

RIBOFLAVIN IN FISH FLESH

Species	μg. per 100 g.
Cod	45·8–310[1]
Haddock	165[1]
Halibut	185[1]
Mackerel	660[1]
Herring	104·4–418[1]
,, (kippered and canned)	300[2]
Brisling sardines	410–620[1]
Salmon (canned)	195–250[10]

It will be seen that whilst fish flesh is rather a poor source, comparable with meat, fish roe is a very good source. According to Lunde,[2] fish liver is also a good source, cod-liver containing 800μg per 100 g. Ox liver contains 1000 to 300μg per 100 g.[1] From Lunde's results on canned kippers, it would appear that neither smoking nor canning have any serious destructive effect on the riboflavin in fish.

TABLE VIII

Riboflavin in fish roe and milt[1]

Material	μg. per 100 g.
Cod roe	900–1130
„ milt	333–440
Haddock roe	1420
„ milt	610
Herring roe	385
„ milt	530
Mackerel roe	1140

Nicotinic Acid

Fish flesh is roughly equal to lean meat as a source of nicotinic acid, as can be seen from Table IX. Fish roe, milt and liver closely resemble fish flesh in content of nicotinic acid.[11,12] Salmon is a good source of this vitamin, which appears to be stable to smoking and canning.

TABLE IX

Nicotinic acid in fish flesh

Species	Mg. per 100 g.
Cod	1·7–3·0[11]
„ (canned)	1·7[12]
Herring	2·9–4·0[11]
„ (kippered and canned)	3·4[12]
Salmon	8·4[11]
„ ("preserved")	6·0[11]
Ling	2·7[12]
Mackerel	5·5–7·2[12]
Halibut	3·0–3·5[13] ; 6·08[12]
Haddock	0·9[13]
Meat	4–6

Pyridoxine (Vitamin B_6, Adermin)

Although it has not been definitely established that pyridoxine is essential in human nutrition, Table X has been reproduced for the sake of completeness from a paper by Lunde[2] ; it shows the potencies of various fish products, relative to other foodstuffs, the pyridoxine content being expressed in "rat units." It will be seen that cod-liver and roe are outstandingly rich, whilst the flesh of certain fish is also very good. The vitamin is apparently stable to canning.

TABLE X

PYRIDOXINE (VITAMIN B_6) IN FISH AND OTHER PRODUCTS

Material	"Rat units" per 100 g.
Brewers' yeast, dry	500
Wheat germ	500
Cod liver	400
,, roe, canned	300
Maize	250
Plaice flesh	100
Brisling (sprats)	100
Sild (small herrings)	100
Cod milt	100
Herring milt	50
Cod flesh	50
Milk	20
Egg white	10

VITAMIN C

Very scanty data are available for the vitamin C content of fish flesh, and such as there are relate mainly to foreign species. It would appear, however, that in general fish flesh resembles meat in containing about 1 mg. to 5 mg. vitamin C per 100 g. Salmon flesh has been reported to be exceptionally rich in this vitamin, even richer than orange juice,[1] but Pyke and Wright[8] were able to find none in canned salmon and only small amounts in a chilled salmon. Fish liver and roe, however, appear to be good sources, approximating to orange juice in potency. How this vitamin is affected by processing is not clear, but the results of Pyke and Wright suggest that considerable destruction must take place. Some values are given in Table XI.

TABLE XI

VITAMIN C IN FISH PRODUCTS

Material	Mg. per 100 g.
Cod liver	26·7[1]
,, roe	3–160[1]; 30[2]
Haddock roe	10[2]
Herring roe	20[2]
Mackerel roe	40[2]
,, milt	5[2]
Salmon flesh	89·9–215·6[1]
,, ,, (chilled)	9[8]
,, ,, (canned)	Nil[8]

Before leaving the subject of vitamins, I should mention that invertebrates, such as shellfish and crustaceans, appear in general to be very similar to fish as sources of the various vitamins, and this applies also to their organs, such as roes.

When we consider fish as sources of certain essential minerals, invertebrates will require separate mention, because in many instances they differ sharply from true fish.

In Tables XII and XIII are given data for the three mineral elements of most significance in nutrition, apart from those that have been taken as "trace" elements. These tables have largely been extracted from the monograph by McCance and Widdowson[14] and cover the edible portions of the principal species of British food fishes, and shellfish and crustaceans respectively. In some instances the results refer to cooked fish, but wherever possible I have taken the results for raw fish, and have also checked the figures for cooked against those for raw. McCance and Widdowson's figures are also in general agreement with those of Nilson and Coulson[15] except for the high content of calcium in shellfish and crustaceans, where the latter authors' values are generally about 50 mg. to 60 mg. per 100 g. It is known, however, that the mineral content of shellfish is liable to enormous fluctuations depending on locality (i.e., the composition of the water) and food supply, and the same may well be true for crustaceans.

TABLE XII

MINERAL CONTENT OF FISH FLESH (MG. PER 100 G.)*

Species	Calcium	Magnesium	Phosphorus
Cod	15	20	240
Haddock	40	25	220
Whiting	40	30	190
Hake	20	25	220
Ling	20	35	220
Dogfish	15	20	270
Lemon sole	20	20	245
Plaice	20	25	220
Average white fish	25	25	225
Herring	100	30	270

* To nearest 5 mg.

TABLE XIII

MINERAL CONTENT OF SHELLFISH AND CRUSTACEANS (MG. PER 100 G.)*

Shellfish	Calcium	Magnesium	Phosphorus
Cockle	125	50	205
Mussel	140	20	235
Oyster	185	40	265
Scallop	115	40	340
Whelk	55	160	225
Winkle	150	385	250
Crustaceans			
Crab	29	50	350
Lobster	62	35	280
Prawn	145	40	350
Shrimp	320	105	270

* To nearest 5 mg.

It can be seen from Table XII that white fish are excellent sources of magnesium and phosphorus, although rather poor in calcium. Herring, however, is much richer in the latter, due to the adventitious presence of small bones, which cannot be removed from the flesh and are eaten with it. Canned fish is richer in edible bone material owing to the softening which takes place—e.g., in canned salmon. Since McCance and Widdowson's data refer to material obtained in British waters, the high calcium content of their shellfish and some crustaceans is worth noting. The high magnesium content of some specimens is also interesting. Table XIV shows the amounts of certain trace elements in the edible portion of fish, shellfish and crustaceans. In shellfish Coulson[17] has shown that the iron and, especially, the copper contents vary enormously according to locality, probably depending on the food supply. Thus, for the Atlantic oyster he found an iron content ranging from 2·1 mg. to 16·7 mg. per 100 g. and a copper content ranging from 0·34 mg. to 13·7 mg. per 100 g. The variations for fish are of a similar range for iron, but less wide for copper. Fish contains less iron than lean meat (about 3·0 mg. per 100 g.), as would be expected in view of the lower blood content, about the same amount of copper, and about 100 times as much iodine. Shellfish are outstandingly good sources of iron and copper and, like all marine products, are also rich in iodine. The high copper content is partly due to the presence of haemocyanin instead of haemoglobin, but oysters at least also contain copper in some other form, not bound to protein.[17] Crustaceans resemble fish in iron content, but have more copper, as would be expected in view of the presence of haemocyanin.

TABLE XIV

TRACE ELEMENTS IN FLESH OF FISH, SHELLFISH AND CRUSTACEANS (MG. PER 100 G.)*

Material	Iron	Copper	Iodine
Fish	0·34–2·5[14,15,16] (0·8)	0·04–0·41[14,15,16] (0·15)	0·01–0·51[15] (0·17)
Shellfish	2·1–26·0[14,17] (8·5)	0·34–13·7[17] (3·7)	0·03–0·04[15]
Crustaceans ..	0·7–2·2[14,15] (1·45)	0·3–1·6[15] (0·6)	0·02–0·04[15]

* Estimated average values in brackets.

It will be seen from this account that as a source of vitamins and minerals, fish are in most respects either equal or superior to meat. At the same time it has been shown that great fluctuations may be encountered in the content of certain constituents, even within a species. Results obtained by analysis of a single specimen may be very misleading.

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CHAPTER XXV

THE EFFECT OF COOKING ON FISH

By L. C. Baker

Introduction

The cooking of fish has received very little consideration from scientific workers. Indeed, the monograph by McCance and Shipp[1] on *The Chemistry of Flesh Foods and Their Losses on Cooking* appears to contain the only really systematic study of the subject. There are a few other odd pieces of relevant information to be found in the literature, but some of these are of very doubtful value. Why fish has been neglected to this extent is rather difficult to say. Fish appears on the menu under an enormous number of exciting pseudonyms, many of which refer to the piquant sauces served with it. Yet the number of basically different methods of cooking fish are few and relatively simple. Herein perhaps may be found one possible explanation—fish is easy to cook. No great skill is required to produce a palatable, cooked product although great skill may be exercised in enhancing its flavour and succulence. Fish does not possess a stubborn toughness to be overcome by the use of special cooking techniques. In fact, in respect of toughness it may be said that the flesh of white fish varies far less from place to place in any one fish, from fish to fish in one species, or indeed from species to species, than does the flesh of beef, for example, from cut to cut in one animal. Fish is usually cooked in small pieces which require only a relatively short heat treatment, often a matter of a few minutes; consequently the complications and difficulties that arise in cooking large pieces of meat, due to the poor heat conductivity of muscle tissue, do not often occur in the cooking of fish.

In discussing the cooking of fish it is almost inevitable to compare it with meat. Both meat and fish consist essentially of muscle tissue together with more or less connective tissue. When it is heated the muscle tissue of fish behaves in a manner similar to that of meat, in that it shrinks and becomes firm. Unlike meat, fish muscle does not show any marked change in colour on cooking. In the majority of the common food fishes, the so-called white fish, the muscle is white or greyish in colour and remains so after cooking.

The structure of fish muscle is often dismissed briefly in text-books by saying that it is similar to that of meat. While that may be so from the point of view of histology, from the more practical point of view of cooking there are certain differences in conformation and composition. One of these is revealed by cooking, in that fish tends to break up into flakes, whereas meat remains close textured unless it is cooked for a considerable time. Fish muscle contains much less connective tissue than meat and is, therefore, much more tender; Reay[2] found that the average extra-cellular protein of haddock muscle was about 5 per cent., whereas Bate-Smith[3] gave figures of 15 per cent. for rabbit and 8 per cent. to 22 per cent. for beef. It is not necessary to consider the effect of cooking on the toughness of fish. In fact, fish cannot be said to be tough except after it has been preserved by one of the less desirable methods such as (*a*) slow freezing and storage at relatively high freezing temperatures or (*b*) as dry salt cod; such fish becomes dry and fibrous in texture.

Food fishes are commonly divided into two classes, white fish and fatty fish. Two families, the gadoids, such as cod, and the flat fishes, such as plaice, include most of the white fish, whose edible muscle contains only a very small amount of fat—of the order of 0·5 per cent. to 2·0 per cent. The muscles of the fatty food fishes, many of which belong to the herring family, may contain up to about 20 per cent. of fat, but this amount of fat varies with the season and with the sexual maturity of the fish. Moreover, the fat in fish is not distributed in the same way as in meat; there is no layer of surface fat corresponding to the back fat in meat.

One further difference between fish and meat must be emphasized, because it affects the duration of the cooking treatment and the extent of the changes which occur. The edible parts of the common food fishes are normally much smaller and thinner than those of beef, mutton, or pork. Moreover, fish is usually cooked in small pieces, seldom exceeding an inch or two in thickness, whereas meat is often cooked in much larger and thicker pieces. Small flat fish may be grilled whole; split fish, such as kippers or smoked haddock of similar size and shape, are cooked whole; the fillets are removed from larger flat fish and grilled or fried; larger fish of the gadoid family are usually cut into small pieces and cooked by boiling, steaming, or frying—less often larger pieces of the whole fish are cooked; occasionally relatively large fish, such as salmon, are cooked whole.

Turning now to the experimental study of the cooking of fish I have to draw almost entirely on the data of the monograph by McCance and Shipp (*loc. cit.*); these were obtained mostly with white fish.

Cooking in Steam

McCance and Shipp (*loc. cit.*) determined the loss in weight on steaming, by placing a number of 2 oz. pieces of one kind of fish in a steamer. They supported the pieces on a wire grid, removed one piece of fish at intervals and weighed it immediately. The liquid expressed during steaming dropped through the grid and the fish did not become water-logged; the saturated atmosphere prevented the loss of water by evaporation. They argued that by this method of cooking they could study the effect of the shrinkage of the tissue on heating without the complications of (*a*) loss of water by evaporation (as in roasting or baking), and (*b*) loss of soluble constituents by

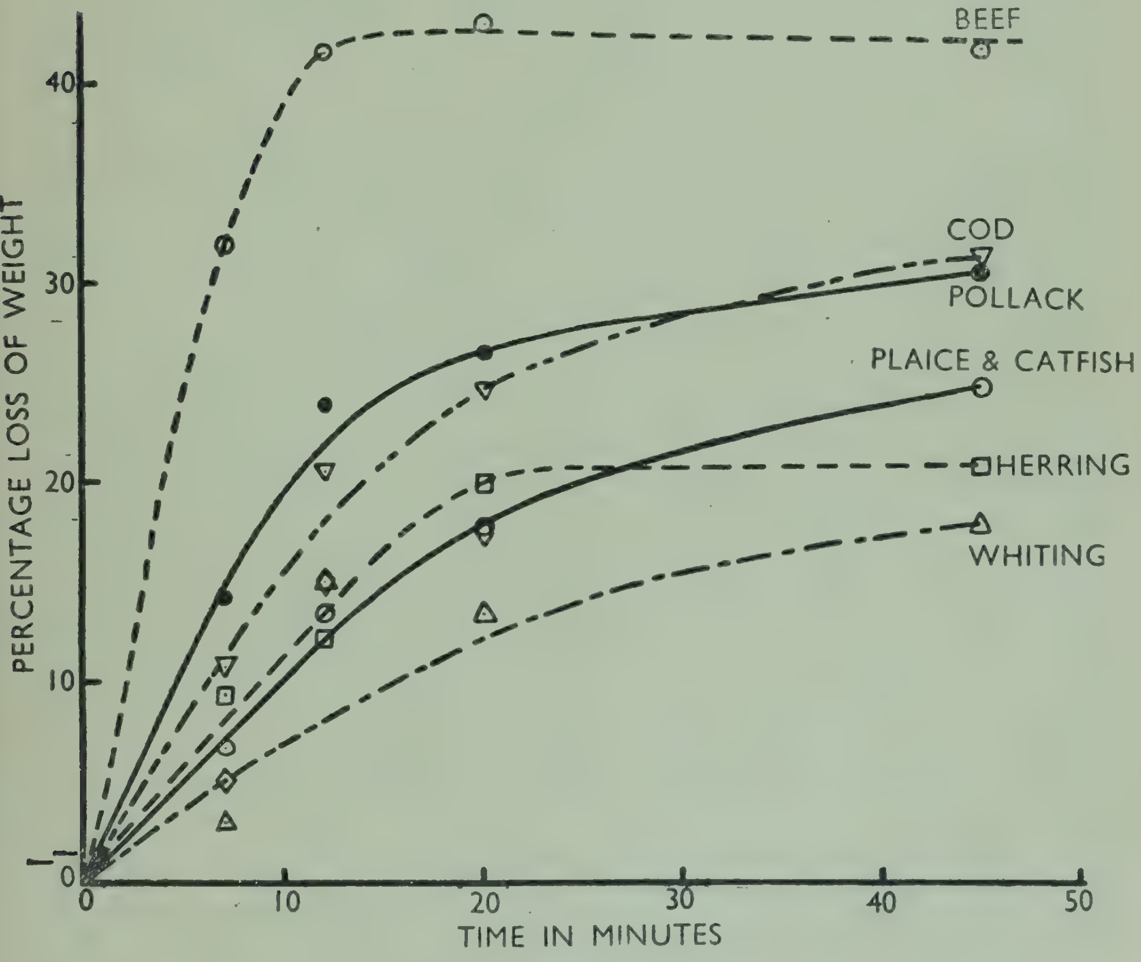

Fig. 1

Steaming 2 oz. pieces

leaching (as on boiling in water). The loss of weight was, therefore, a measure of the degree of shrink. This experiment was repeated for a number of different kinds of fish. The results obtained are shown in Fig. 1, in which the percentage loss in weight is plotted against the time of steaming. For purposes of comparison some results for beef are included. The curves bring out two interesting points: (*a*) fish muscle shrinks more slowly and to a smaller extent than beef; after 45 minutes' steaming the percentage loss of weight was of the order of 20 per cent. to 30 per cent., compared with 43 per cent. for beef; (*b*) different kinds of fish appear to shrink at different rates and to different degrees, although the curves indicate that the shrink is not completed in 45 minutes. It was also found that, if the losses of water and the soluble constituents K, P, and Cl during cooking are expressed as percentages of the amounts of those constituents in the raw fish, then the percentage losses of the soluble constituents follow closely those of water; this supports the view that a liquor of constant composition is expressed when fish shrinks. The composition of the liquor lost was water 94·5 per cent., protein 4·7 per cent., salts 1·0 per cent., and fat 0·8 per cent.

It has been pointed out above that fish is usually cooked in small pieces and these results of McCance and Shipp are therefore applicable to the practical cooking of fish. When a piece of fish is "done" is a matter of judgment; in cooking small pieces of fish by steam, it is probably after about 20 minutes. I have not found any studies in which an attempt has been made to correlate the temperature reached at the centre of a piece of fish with doneness, although much attention has been paid to this aspect of the roasting of meat. Tarr[4] studied the effects of freezing and brining fillets of halibut on the loss of liquid which occurred when the thawed fillets were subsequently processed in sealed cans at two different temperatures, namely 212° F. and 248° F. (10 lb. pressure); each can contained two fillets, each weighing 5 oz., and was processed for 30 minutes at the retorting temperature after 30 minutes had been allowed for that temperature to be reached. In the first experiment 16 fillets were cut from a fresh halibut; half these fillets were frozen in still air at 18° F. and, after 24 hours at this temperature, were stored for another 24 hours at 25° F. before thawing. These fillets were, therefore, exposed for 2 days to temperatures at which denaturation of the protein is known to proceed rapidly. The remaining fillets were kept at 35° F. for 1 day. Those fillets which were brined were allowed sufficient time in the brine for the flesh to absorb 1 per cent. of salt. After processing and cooling, the cans were opened and allowed to drain, and the quantity of expressed liquid was measured. A similar experiment was carried out with fillets cut from a halibut which had been frozen in still air and stored at least 6 months in the frozen state.

The results obtained are here summarized.

TABLE I

	Percentage loss of weight on processing 212° F.	 248° F.
Fresh Halibut—Expt. I—		
Unbrined, unfrozen	19·5	23·3
,, frozen	16·7	20·0
Brined, unfrozen	19·7*	22·9*
,, frozen	15·8*	18·6*
Cold stored Halibut—Expt. II—		
Unbrined	8·5	12·1
Brined	8·2*	11·9*

* Based on weight of fillet after brining.

It is probable that in these experiments a certain amount of water-logging of the flesh occurred, but the results are comparable among themselves. The results show (i) that in all instances the higher processing temperature resulted in an increase of 3 per cent. to 4 per cent. in the loss of weight; (ii) that brining had no significant effect on the loss of weight on processing of either raw or frozen fillets; (iii) that freezing and storage under poor conditions resulted in an appreciable decrease in the percentage loss of weight (expressed liquor) in both brined and unbrined fillets at both processing temperatures. For unbrined fillets processed at 212° F. the freezing and short storage period used in Expt. I resulted in a decrease of the percentage loss of weight from 19·5 per cent. to 16·7 per cent.; for similar fillets in Expt. II, after 6 months' storage in the frozen state, the percentage loss of weight on processing fell to 8·5 per cent. The author concluded that this result supports the view that the type of denaturation of the proteins occurring on freezing and cold storage under poor conditions differs from that occurring on heating. Further support for this view was obtained from the observation that the frozen halibut after processing contained large amounts of curdy material and was noticeably drier and tougher than unfrozen material.

Cooking in Water

McCance and Shipp (*loc. cit.*) found that fish lost rather less weight when it was cooked in water than when it was cooked in steam. They considered this difference to be apparent rather than real. When fish is heated it tends to break up, cracks appearing between the flakes of muscle; the fish thus becomes water-logged by virtue of the water held in these cracks, and it appears that after a time the water held practically balances the liquor lost by shrinkage. It will be remembered that in steaming the percentage loss of soluble salts was practically the same as the percentage loss of water, but when fish is cooked by boiling the percentage loss of soluble salts is greater than that of water, indicating that the loss of salts by leaching, apart from the losses in the liquor expressed by shrinkage, is very considerable. It is also interesting to note that McCance and Shipp found that the loss of protein on steaming and boiling fish, although small, was much greater than for meat.

Little can be said concerning any differences between the behaviour of various kinds of fish on boiling. A few results obtained by McCance and Shipp indicate that catfish loses rather more weight than the two closely related species, cod and pollack. In this connection reference may be made to some results published by Williams[5] in 1911 for about 25 different kinds of fish cooked by boiling in water. Losses in weight ranging between 6·2 per cent. and 41·3 per cent. are recorded, but these are of doubtful value because the time of cooking is not recorded and it is not very clear what weight of fish was used. In the same year, Ulrich[6] published results for cooking seven different kinds of fish in water, and found percentage losses of water ranging between 2·5 per cent. and 11·7 per cent. As McCance and Shipp have shown that loss of water and weight are practically the same, the discrepancy between the two sets of results is apparent.

COOKING BY BAKING AND FRYING

McCance and Shipp studied the losses which occurred when 2 oz. pieces of fish were roasted in an oven and their results make it clear that in roasting the losses of weight and water are very considerable and very rapid, and show no tendency to reach a steady value, as in cooking in steam or water; this is due to the continuous loss of water by evaporation, which is the dominant factor in roasting. On the other hand, the percentage loss of soluble salts is very small, much smaller than in steaming or boiling, because the liquor expressed by shrinkage is largely evaporated, leaving the salts behind as a deposit, and also because there is no loss of salts by leaching. It may be said that in roasting fish behaves like meat, whereas in both steaming and boiling certain differences in degree were noted.

Fish is very often cooked by coating it with a batter and frying it in deep fat. This method of cooking is similar to roasting or baking in its effect, in that the dominant factor is loss of weight by evaporation of water and consequent maximum retention of salts.

Table II gives the percentage losses of the chief constituents of white fish on boiling, steaming, and frying.

As a matter of interest, it may be stated that when fillets of fish were fried for 3 minutes in an oil bath at 220° C. falling to 200° C., we have recorded a temperature of 65° C. at the centre at the end of the frying period, rising to as high as 87° C. after the first 3 minutes of the cooling period.

TABLE II

	Catfish—percentage losses		
Weight	28·0	24·5	24·0
Total nitrogen	6·6	5·6	0·1
Purine nitrogen	17·6	15·8	1·7
Non-protein nitrogen	35·0	23·6	2·1
Na	39·5	31·0	4·4
K	39·6	29·8	3·4
Ca	21·6	16·4	6·4
Mg	27·5	23·0	5·2
P	30·0	24·0	2·9
Cl	43·5	35·0	2·3

The Effect of Cooking on the Composition and Nutritional Value of Fish Flesh

Table III shows the changes in general composition which take place when fresh white fish is steamed or fried; the figures for fresh white fish were obtained by averaging the figures given for cod, haddock, megrim, and plaice by McCance and Widdowson[7] and by McCance and Shipp[1] and the figures for steamed and fried fish are taken from the monograph of the latter authors.

TABLE III

	Fresh	Steamed	Fried
Water	80·7 per cent.	75·4 per cent.	61·5 per cent.
Protein	16·4 „	22·4 „	19·3 „
Fat	1·1 „	1·4 „	11·9 „
Carbohydrate	—	—	6·4 „
Water : Protein ratio	4·9	3·4	3·2
Calories per 100 g.	76	100	215

The protein figure is true protein obtained by multiplying by 6·25 the difference between total nitrogen and extractive nitrogen. In fried fish the carbohydrate comes from the batter used and the marked increase in the percentage of fat is due to the fat picked up from the oil bath. These results for fried fish are in general agreement with those obtained by Kobert.[8] The results for water and protein show that the shrink caused by cooking has resulted in a decrease in moisture and an increase in protein, the water protein ratio decreasing from 4·9 to 3·2–3·4; the percentage of protein in fried fish is lower than that in steamed fish because the former has taken up fat and carbohydrate.

A table such as this enables the nutritional value of a given weight of steamed or fried fish to be worked out rather crudely in terms of calories and weights of protein fed. But it does not give any idea of the extent to which the material eaten is digested and absorbed. There can, I think, be little doubt that the particular nutritional value of fish, white fish at any rate, is as a source of animal protein. The digestibility and biological value of protein are specialized and difficult subjects which I do not propose to discuss, except in so far as they are affected by cooking. In a review of the subject written in 1935, Boas Fixsen[9] remarks that until recently it was thought that the value of protein was not lowered by exposure to temperatures involved in such methods of cooking as boiling and steaming. Towards the end of the last war, Drummond[10] found the nutritive value of the muscle tissue of herring, cod, and salmon to be equal to that of meat; he prepared these materials for inclusion in the diet as a coagulum by boiling an aqueous suspension of the minced tissues. Scheunert[11] *et al.* found no difference in the growth records of rats fed on diets containing raw, boiled, fried, or autoclaved meat. On the other hand, Morgan and Kern[12] noted a decline in the value of beef after boiling or autoclaving until the internal temperature reached 84° C.

For fish proteins Maynard and Tunison[13] found a loss in the digestibility and the biological value of meals made from both haddock waste and menhaden fish by direct flame drying at a maximum temperature of 380° F. compared with meals prepared in a rotary vacuum dryer which showed a minimum temperature in the drum of 133° F. and a maximum near the walls of 240° F. More recently, Saha[14] compared the digestion of raw, fried, boiled, and partially boiled fish *in vitro* by pepsin, by trypsin, and by pepsin followed by trypsin. He found partially boiled fish to be rather better digested than the other three forms, but concluded that *in vivo* the breakdown of fish proteins would be fairly complete. Clearly there is insufficient evidence from which to draw any definite conclusions about the effect of normal cooking treatments on the utilization of fish protein by the body.

That fish may have other special digestive virtues apart from those already mentioned was indicated in reports by Babkin,[15] Alley,[16] and Campbell.[17] A series of observations was recorded on the amount and characteristics of the gastric juices secreted as the result of ingestion of meat, fish flesh of different kinds and fish skins. The authors found that the presence in food of fish skin or of substances extractable from it produced a gastric secretion from one-third to one-half greater than did the corresponding flesh alone; the gastric juice produced by the food containing skin was as strong in digestive power but rather more acid than that produced by flesh alone. The amount and quality of the gastric juice secreted as the result of ingestion of the flesh of fish varies from species to species.

Lobster induced a greater flow of juice and digestive enzyme than cod, haddock, or mackerel, which all caused a similar volume of juice to be secreted, but the amount of digestive enzyme was greatly suppressed by mackerel, owing to its higher fat content.

Finally, the investigation dealt with the identification in the juices from cod and meat of the substances which stimulate the flow of the gastric juices. It was claimed that the nitrogenous bases form two-thirds of the nitrogenous material in the juice of cod and are responsible for 99 per cent. of the gastric secretion. The "histamine fraction," which amounts to one-tenth of the material, caused 49 per cent. of the secretion; histamine is very active in causing gastric secretion poor in pepsin and high in acid. Choline, on the other hand, stimulates a secretion high in pepsin and poor in acid. The juice of cod flesh contains over twice as much of the "choline fraction" and much less than half as much of the "histamine fraction" as meat juice. Therefore, compared with meat, cod flesh stimulates a secretion higher in pepsin and lower in acid.

In conclusion, it is hoped that this chapter has indicated how much remains to be done in this field of investigation.

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Part VII

MILK AS FOOD

(Papers read at a meeting on 3rd *July,* 1943)

CHAPTER XXVI

THE CHEMICAL COMPOSITION AND NUTRITIVE VALUE OF MILK AND MILK PRODUCTS

By S. K. Kon

The Normal Composition of Milk and its Variations

The composition of milk as it is known at present is given in Table I; Fig. 1 shows the contribution of 1 pint of milk to the daily requirements of a moderately active man and of a five-year-old child. The calculations are based on the latest American proposals[1].

TABLE I

The composition of milk

(Pasture, English)

100 g. contain

87·6 g. Water, 12·4 g. Total solids, 66 Calories

Protein	3·3 g.	Calcium	0·12 g.
Fat	3·6 g.	Phosphorus	0·10 g.
Carbohydrate	4·7 g.	Magnesium	0·01 g.
Iron	0·03 mg.		
Vitamin A Carotene	150 I.U.	Vitamin B_6	30 μg.
		Biotin	5 μg.
Vitamin B_1	45 μg.	Inositol	14 mg.
Riboflavin	150 μg.	Vitamin C	2 mg.
Nicotinic acid	80–400 μg.*	Vitamin D	2 I.U.
Pantothenic acid	400 μg.		

* Depending on method of measurement.

It is generally recognized that the value of milk as food lies chiefly in its content of protein of high biological value, its exceptional richness in calcium and its generous supply of vitamin A, riboflavin, and other members of the vitamin B complex. In fact one pint of milk supplies seven-eighths of the calcium, over one-quarter of the protein, slightly less than one-third of the riboflavin, and just under one-fifth of the vitamin A recommended for a moderately active man. For the child the contributions are not only larger but more uniform, indicating the special value of milk for the young. The protein is first-class animal protein and vitamin A is mostly supplied as the preformed more assimilable substance. The great value of the proteins of milk lies in their ability to enhance the biological value of the proteins of such staple vegetable foods as cereals and potatoes. Thus, for example, a combination of bread and cheese had, when tested on rats, the same biological value, 75·5, as cheese, though bread alone had a value of only 52·0 ; similarly a combination of milk and potato had a biological value of 86, almost as high as that of milk, 87, though potato alone had a value of only 71. The interesting point is that if the two substances are given separately on alternate days there is no evidence of a supplementary relationship. Old food customs thus receive scientific support. It is probably not so well known that milk is also an appreciable source of vitamin B_1, one pint supplying one-seventh of the daily needs of the adult and one-third of those of the child. In the United States before the introduction of enriched bread, milk was the second most important single source of this factor. Fig. 1 also shows that a pint of milk could supply one-quarter of the vitamin C needed by a child. Unfortunately, this does not happen in practice for reasons to be explained later. The agreement between the various methods of estimating nicotinic acid in milk is far from good and it would be prudent for the present not to rely on milk for the supply of this factor. Finally, of iron milk contains only negligible quantities and, as a matter of fact, an exclusive diet of cow's milk is the favourite way in the laboratory of producing nutritional anaemia in rats or mice. In this connection a curious fact may be mentioned parenthetically. In most species the shortage of milk in iron is compensated by the body stores of the young. In the pig, however, the reserves are too small to cope with the enormous rate of growth and, even when the sow has access to the most luscious natural diet, the piglets must be given or obtain additional iron or else they rapidly die of extreme anaemia.

Several reports have come lately from the United States and also from Sweden and Holland to the effect that the fat of milk is superior in nutritive value to vegetable fats. This is apparently a property of the fat itself and not of any accompanying vitamins. While not denying this possibility I must say that repeated experiments carried out at Shinfield in the last few years have completely failed to demonstrate such difference.

Milk is a variable product and its composition, especially with regard to the so-called minor constituents, varies markedly according to the season of the year and the breed, nutrition, and health of the cow. The values just outlined apply to mixed English milk produced on pasture and it might be instructive to outline briefly the magnitude of the normal variations and to enquire into their causes.

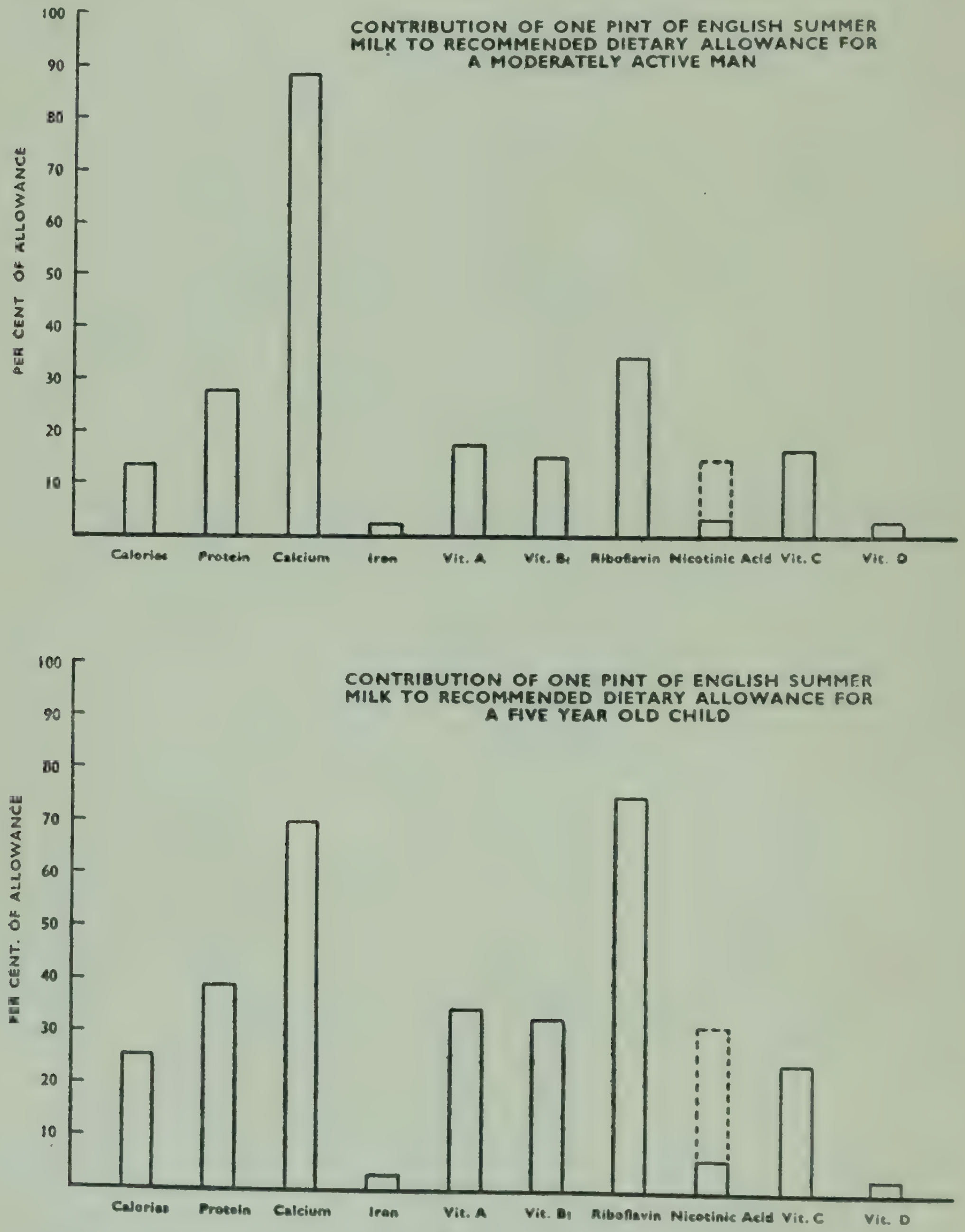

FIG. 1

CONTRIBUTION OF ONE PINT OF MILK TO THE DAILY REQUIREMENTS OF A MAN OR OF A CHILD

The calorie value of milk varies primarily with its fat content and is naturally higher for the milk of the high fat breeds, Jerseys and Guernseys, than for the milk of Shorthorns, Friesians, or Ayrshires. Changes in protein, calcium or phosphorus content are normally small enough to be disregarded but fluctuations in the vitamin A activity are profound. They are mostly related to the fodder of the cow. The carotene of grass, hay, silage or kale appears in the milk partly as vitamin A and partly in its original form. In late spring, summer and autumn when grass is abundant or kale is fed the vitamin A activity of milk is at its best ; in the south of England it declines steadily from November to reach its lowest point in April just before cows go out to grass. Summer milk in this country has a potency of 40 or 50 I.U. per g. fat. In early spring the value may fall to 10 units to 20 units. Even at the same time of the year differences in managment of the cows may produce profound variations in the vitamin A activity of milk. We thus found last May that milk from a town dairy in Liverpool had only one-fifth of the potency of milk from a Devonshire creamery. As a rule in the milk of any one breed the concentrations of carotene and of vitamin A are roughly parallel and the degree of yellowness of the cream is a good guide to the vitamin A potency of the milk. The rule breaks down when it comes to inter-breed comparisons. The richer yellow of Guernsey and Jersey milk indicates not necessarily a higher vitamin A potency, but the relative inefficiency of these breeds as converters of carotene. With access to the same pasture a Guernsey puts more carotene and less vitamin A into her milk than a Shorthorn, but the total potency per g. fat is the same for both. In the end, however, the Guernsey wins, as her milk contains more fat.

The vitamin B_1 of cow's milk is remarkable independent of the feed and is in all probability formed in the rumen by bacterial synthesis. In bulk milk the level remains more or less constant throughout the year, but for individual cows it is higher in early than in later lactation. Riboflavin is to some extent dependent on the feed of the cow, but the connection is not clear cut as synthesis in the rumen also plays a role. Mixed milk in this country usually contains between 140μg. and 180μg. per 100 ml. The milk of the Channel Island breeds is richer in riboflavin than that of other cattle and values of up to 250μg. per 100 ml. may be encountered. Information about the presence in milk of the other members of the vitamin B complex is still fragmentary ; it is known, however, that pantothenic acid, vitamin B_6, and biotin are synthesized in the rumen.

Vitamin C is also synthesized by the cow, but it is not known where. Certainly not in the rumen, in which the relatively enormous quantities of ascorbic acid contained in fresh grass are rapidly destroyed. The level of vitamin C in milk as it leaves the udder is under effective physiological control and remains remarkably constant despite changes in season and in feeding and management of the cows. Yet in commercial milk vitamin C is one of the most variable factors and the consumer seldom gets more than a fraction of the quantity originally present. The explanation lies in the interesting phenomenon of induced photochemical oxidation of vitamin C by daylight. Vitamin C itself is colourless, that is, it does not absorb visible light ; riboflavin, however, which is yellow, absorbs blue light and acts as a sensitizer. The effects of light are rapid and dramatic. Thus, a pint bottle of milk left on the doorstep in the usual way for half-an-hour and then placed in the larder loses by the time it is consumed fully half of the vitamin C originally delivered by the milkman. The destruction is in stages : under the action of light vitamin C is transformed into dehydroascorbic acid ; this though still biologically active is unfortunately not stable and decomposes further even in darkness. There are two ways of preventing loss of vitamin C from this cause. First, exposure to light may be avoided. Cartons, for example, give a good degree of protection. Brown glass bottles would be ideal, but it is very doubtful whether they would catch on. Secondly, as oxygen is needed for the reaction its removal from milk abolishes the action of light. Much interesting work has been done on this aspect of protection in America, where it is now a commercial possibility. Though the phenomenon was first observed in this country it has elicited little practical interest, probably because the nutritive properties of milk are as yet not a selling point here.

A further factor of practical importance contributes to fluctuations in the levels of all water-soluble vitamins in milk. Subclinical mastitis lowers appreciably their concentration, and it is not unusual to observe in the same cow differences amounting to 25 per cent. between the secretions of a healthy and of a diseased quarter of the udder.

Under normal feeding conditions the vitamin D of milk is almost entirely derived from the direct action of the sun on the skin of the cow and in summer the sun contributes all and the pasture none of the increase in the vitamin D potency usual at this time of the year. During the stall feeding period a little vitamin D is obtained from hay. The vitamin D content of milk is highest around the summer solstice and falls off sharply on either side. The winter values are about 0·1 I.U. per g. fat. In summer they may be 5 to 8 times higher.

Though the normal vitamin D content of milk is much too low to be of practical value, it may be increased to useful levels and it is generally agreed that such enriched milk is most valuable in the prophylaxis of rickets. There are, roughly speaking, three distinct methods of producing such vitamin D in milk, direct irradiation, addition of vitamin D concentrates and the feeding to cows of irradiated yeast. All three methods are used on a large scale in the United States and the irradiation of milk was becoming increasingly popular in Germany. In Britain for some reason vitamin D milk has not been used to any extent.

It should be clear that, nutritionally speaking, milk even in the raw state is, as it reaches the consumer, a highly variable product.

Effects of Heat Treatment and of Processing

It will be apposite now to compare the extent of these so-called normal variations with changes arising from heat treatment or processing of milk.

Pasteurized milk.—A large part of the commercial milk supply in this country is pasteurized, mostly by the holder method, which consists in bringing the milk to 145° F. to 150° F., and keeping it at this temperature for 30 minutes. It has been definitely established in laboratory experiments that the only nutritive losses caused to the known constituents of milk by this type of procedure are a destruction of some 20 per cent. of vitamin C and of about 10 per cent. of vitamin B_1. The loss of vitamin C is largely brought about by previous exposure of the milk to light, as milk as it comes from the udder may be pasteurized without any loss. The enzymes of milk are also destroyed in the heat treatment; indeed, the destruction of the enzyme phosphatase forms the basis of the most delicate test for efficiency of pasteurization. This destruction is naturally without any nutritional significance, as the phosphatase of milk would not in any event survive passage through the stomach. The so-called flash or high-temperature short-time method of pasteurization is also coming into operation here. Its effects are even slighter than those of the older method.

Large-scale experiments carried out in Great Britain in the last few years to assess the value for children of milk, raw and pasteurized, have unequivocally shown the nutritional benefits derived from extra milk, but have failed to show any difference in this respect between the raw and heated varieties.

Sterilized milk.—In London and in some Midland centres, especially Birmingham, there is a demand for the sterilized variety of liquid milk. It is convenient on account of its excellent keeping qualities, it can be bought from the grocer and it is locally popular because of the "richer" taste. This milk is heated to 212° F. and generally higher for varying lengths of time, and this drastic treatment destroys about half the vitamin C and one-third of the vitamin B_1 originally present. The biological value of the proteins is also slightly decreased.

Dried and condensed milks.—The concentrated stable forms of milk are prepared in three different ways. The water may be removed as completely as possible, giving dried milk powder ; or it is only partly removed and the condensed product is either sterilized by heating to ensure bacteriological purity or has enough sucrose added during manufacture to check bacterial growth. The three methods in various modifications are applied to separated and to full-cream milk.

(1) *Dried milks.*—Of these treatments, drying by modern methods is generally quite mild in its effects. Spray-dried milk is obtained by forcing an exceedingly fine spray of milk into a heated chamber, where it dries almost instantaneously. It is almost completely soluble in water and "reconstitutes" easily. The losses in drying are very much the same as in pasteurization, 20 per cent. of the vitamin C and 10 per cent. of vitamin B_1; in addition, there is a slight deterioration in the biological value of the proteins, not exceeding 5 per cent. for good quality spray-dried milk.

Roller drying consists in rapidly dehydrating a thin film of milk on steam-heated revolving metal cylinders, from which it is removed by means of a stationary scraper. First quality roller dried milk is nutritionally about equal to the spray-dried variety, but it is less soluble in water. As a rule, the loss in vitamin C is nearer 30 per cent. and the deterioration of the proteins is rather more noticeable. Occasionally spray and roller dried milk are encountered, in which, through exposure to naked copper during manufacture, vitamin C is largely destroyed. Other milk constituents, vitamin A and carotene, vitamin D and riboflavin, suffer, as far as it is known, no loss during drying. It is also well established that the availability of the calcium is not impaired by any of the treatments. Full cream dried milks keep quite well for long periods of time in hermetically-sealed containers and an atmosphere of inert gas. They deteriorate, however, on exposure to air. Modifications of the process of manufacture, involving the use of a higher pre-heating temperature, have recently been developed which will greatly increase the stability of milk powders[2].

Cream has proverbially been considered the most valuable part of the milk, and milk with the fat removed has borne a stigma of inferiority. Even now, when the food value of milk is much better understood, there is still widespread prejudice against the use of dried skim milk in human nutrition. Yet, when its limitations are properly understood, it is a most valuable food. The absence of fat and of vitamin A make it unsuitable for babies and in Great Britain it has to be clearly labelled to this effect. All its other important nutrients remain, however, unimpaired, and, for that matter, proportionally increased at the expense of the missing fat. The high content of animal protein, calcium, and riboflavin makes dried skim milk a most valuable addition to many dietaries. Vitamin C, vitamin B_1 and the other members of the vitamin B complex are also there in relatively increased amounts. If protected from moisture, dried skim milk keeps almost indefinitely without need for special packing.

(2) *Condensed milks.*—Of the milk products from which water is only partly removed unsweetened condensed milk, generally known as evaporated, is exposed to the most drastic heat treatment. The concentration itself is carried out *in vacuo* at relatively low temperature, but the milk is then placed in tins, which are sealed and sterilized by heat at a temperature of 240° F. This has drastic effects on the more labile components. Some 60 per cent. of the vitamin C and 30 per cent. to 50 per cent. of the vitamin B_1 are lost, and the digestibility and biological value of the proteins are slightly but unmistakably decreased. The good record of evaporated milk in the feed of infants, shows, however, that, properly supplemented, it remains a food of outstanding value.

Sweetened condensed milk is not exposed to temperatures above the boiling point of water, and frequently the maximum temperature is well below this. The development of bacteria is effectively checked by the cane sugar added before condensing and reaching a final concentration of about 40 per cent. The losses of nutrients during this form of processing are very small and a good specimen may contain only 15 per cent. less vitamin C and 5 per cent. to 10 per cent. less vitamin B_1 than were originally present in an equivalent quantity of the raw milk.

In assessing the food value of different types of milk it should be remembered that dried milks are concentrated about $7\frac{1}{2}$ to $7\frac{3}{4}$ times in comparison with fresh milk, and evaporated milk about $2\frac{3}{4}$ times. Hence the amount of milk solids varies in the different products but the proportion of these solids remains the same. It is altered, however, in sweetened condensed milk by the presence of large amounts of sugar, and this type of milk is richer in total solids than evaporated milk, though the concentration of the milk solids is roughly the same in both.*

Effects of Heat Treatment Compared with Normal Variations in Nutritive Value

Fig. 2 shows a comparison of the effects of various types of heat treatment with the normal fluctuations in the nutritive value of raw milk caused by season, nutrition, and health of the cow, or the usual exposure to light. It is clear that the amplitude of the variation in the raw product far exceeds the changes that are brought about by processing. It should also be remembered that as a rule the drying and condensing of milk take place when milk is plentiful, that is, in the pasture period, and that such treated milk may, in fact, be nutritionally superior to the raw milk available in winter time.

The Role of Milk in Nutrition

Milk occupies among foods an almost unique position in that it is a substance specifically elaborated and designed to satisfy the nutritive demands of rapid growth. Around the acknowledged preeminence of cow's milk as probably the most perfect single food of man there has grown of late a legend crediting nature with the special intention of endowing the human race with this valuable fluid. The legend would have it that as milk is a natural food any interference with the state in which it leaves the cow is harmful if not altogether sinful. The author of the next chapter in this book points out the dangers arising from such an attitude. Sober reflection will also show that it is no more unnatural to heat cow's milk than to cook her flesh, yet few people would seriously offer teleological objections to the latter procedure.

A clear recognition not only of what milk is but also of what it is not will certainly help in the just appraisal of its great nutritional merits. It is unfortunate that in winter and early spring the increased demands of the infant and child for certain dietary factors should coincide with the lowest ebb of these substances in cow's milk. It is possible to produce by dietary means winter milk approximating to summer milk in its nutritional qualities and we should do better to strive towards such a goal rather than to split hairs about the alleged evils of pasteurization, an essential sanitary measure. Agriculture in this country, whether scientific, practical, or official,

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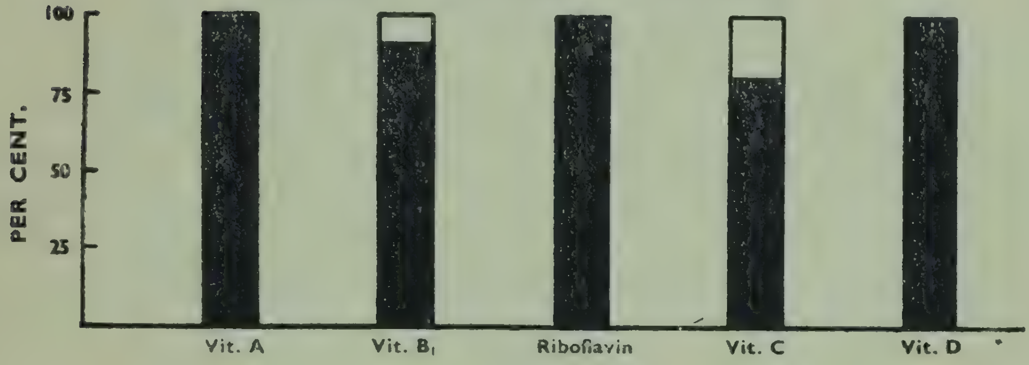
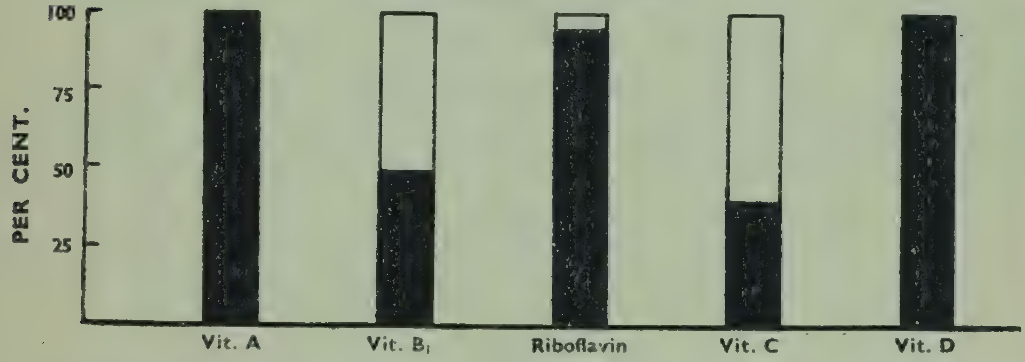
* As a war-time measure the sale of evaporated milk concentrated only about twice was legalized in this country.

LOSS OF MILK NUTRIENTS IN PROCESSING
PASTEURIZED MILK
DRIED MILK
SWEETENED CONDENSED MILK



LOSS OF MILK NUTRIENTS IN PROCESSING
EVAPORATED MILK



NORMAL VARIATIONS IN NUTRITIVE VALUE OF RAW MILK

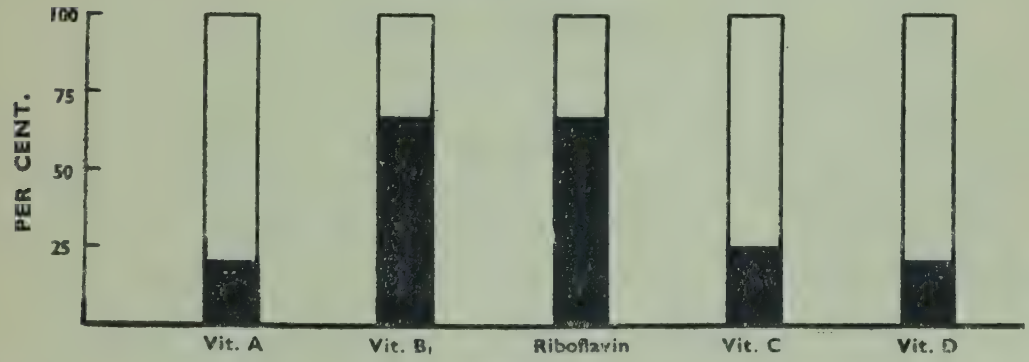


FIG. 2

LOSS OF MILK NUTRIENTS IN PROCESSING COMPARED WITH NORMAL VARIATIONS IN RAW MILK. WHITE AREA DENOTES LOSS OR EXTENT OF VARIATION

displays a keen interest in the forage and fodder value of agricultural products, but is only little concerned with their value in human nutrition. Feeding stuffs are produced, graded, and sold according to their starch equivalent, and protein, and sometimes even carotene, content, yet human foods are treated as if their nutritive value were of no consequence at all. There may be bad hay, indifferent hay, good hay, or excellent hay, but according to pundits and legislators only one kind of fluid comes out of the cow's udder provided it contains more than 3 per cent. fat. There is now, and there was in peace time, no incentive for the farmer to bother at all about methods of increasing the carotene, vitamin A, and riboflavin content of winter milk, preserving the vitamin C of milk or raising its total solids. We have heard a lot about the marriage of health and agriculture ; it is about time there was a more diligent inquiry into the nutritive value of the fruits of this union.

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Note. Full references to the subject of this chapter will be found in several reviews by the author, as follows,—

J. Dairy Res., 1934, **5**, 250; 1936, **7**, 192; 1938, **9**, 242; 1940, **11**, 196; 1943, **13**, 216.

CHAPTER XXVII

BACTERIOLOGICAL ASPECTS OF MILK PROCESSING AND DISTRIBUTION

By A. T. R. Mattick

In spite of the fact that the experience of many years has shown that the public may, by the proper pasteurization of milk, be virtually completely freed from the hazards of drinking raw milk, there is still an influential, if misguided, section of public opinion opposed to its universal use.

The facts concerning certain aspects of pasteurization and particularly those concerned with milk as a vehicle for micro-organisms pathogenic for man, have recently been admirably marshalled[1] and there is no room for doubt in the minds of those who are able to assess their meaning without bias that pasteurization, carried out in plant of approved types controlled by competent workers, should be obligatory. However, this paper is not concerned with the politics but with the bacteriological aspects of the problem. I would say at once that, however desirable pasteurization may be for milk and by-products for consumption, in one or other form, by human beings, it is at least as desirable for stock feeding. It has also to be recognized that for bacteriological and other reasons, such as the destruction or inactivation of enzymes, pasteurization is of great value and importance in dairy manufacture.

I should define the process as heating to some temperature well below boiling point, for a time which varies with this temperature, and if it is grasped at once that the death of micro-organisms, in all conditions where heat is applied, is a function of time and temperature (above a certain minimum) and that the two are inseparable, the infinite flexibility of the process with modern plant will be easily understood.

Objects of pasteurization—From the public health aspect milk is pasteurized to kill the common pathogenic organisms of many kinds which may occur in raw milk. It is perhaps ultimately of little less importance that proper pasteurization of good raw milk so enhances the keeping properties that the consumer is able to make full and unrestricted use of milk in its most acceptable form. If, as I hope to show, milk has not a sufficiently long keeping quality, it is not the fault of the process but of deficiencies in its application and in distribution or in the raw product.

Pathogenic organisms—Interest naturally centres round the pathogenic organisms likely to be present in milk, particularly those of which small numbers may set up serious infection in man, such as the tubercle bacillus and perhaps *Brucella abortus*, and those which can grow freely at ordinary temperatures (typhoid, salmonellas and dysentery). The practice of bulking raw milk for consumption in towns, therefore, imposes a heavy duty on the distributor. Thus it has been shown (Pullinger[2]) that virtually 100 per cent. of bulks of 3000 gallons of milk in tankers containing living tubercle bacilli, sometimes in considerable numbers and always in numbers sufficient to set up infection in the guinea-pig by the usual method, and my own experience (Mattick and Hiscox[3]) with smaller bulks shows that the danger is not confined to large volumes.

The tubercle bacillus, by reason of a resistance to heat in milk rather greater than that of the other more common pathogenic organisms (which in the main may be said to be destroyed at about 140° F. for 10 minutes), has led to its "adoption" as the organism of reference. The requirements for officially sanctioned "Holder" pasteurization are heating at not less than 145° F. nor more than 150° F. for not less than 30 minutes followed by adequate cooling.

The classic work of North, Park and their colleagues[4] with pasteurizing plants showed that tubercle bacilli (human and bovine) in raw milk are killed at 138° F. in 30 minutes. It thus appears that our official regulations embody a large margin of safety. The results of more recent laboratory experiments in this country have been rather equivocal (White, 1926[5]; Meanwell, 1927[6]) as have certain experiments on animals carried out by Zeller and his colleagues in Germany.[7] These experiments suggested that, on occasion, tubercle bacilli in milk might survive pasteurization at temperatures above those laid down by North *et al.* It is clearly of the greatest importance that those who carry out work of this character should use more than the usual care in the design and technique of their experiments and in the care and management of any experimental animals. Nevertheless, it may be well not to dismiss all the inconvenient findings of these workers and to face the possibility,—it is, I believe, no more,—that when *abnormal* milk is heated, local coagulation, by reason of acidity of the milk or because of the presence of flocculi of other types, may sometimes allow the tubercle bacillus to escape destruction, though it is unlikely that under good practical conditions of pasteurization any significant numbers of organisms escape the processing. My reasons for this statement are two-fold: (1) the actual time of exposure in holder pasteurization to a temperature of 140° F. or over always exceeds 30 minutes because emptying time for the bulk of the milk and the time of heating to 145° F. are additional, (2) that a process of filtration is incorporated in the plant, automatically removing particles of a size and nature likely to protect organisms from heat at the temperature used. Filtration is, of course, important for other reasons and has not received the attention it deserves. It may be repeated that the work of North *et al.* was carried out on pasteurizing plants and that examinations of vast numbers of commercially pasteurized samples have given negative results. The proof of the pudding is in the eating. It is certain that in connection with the freedom of milk from living tubercle bacilli, the quality of the raw product is of the greatest importance. In one matter at least, a war-time measure is likely to have far-reaching effects if its general application is not stifled for sectional reasons—the National Milk Testing and Advisory Scheme of the Ministry of Agriculture. The scheme foreshadows payment of the producer on quality, estimated by an acceptable technique, and I do not expect to see the full benefits until this is implemented. Lastly on the question of the tubercle bacillus it ought to be said that before accepting adverse reports from the field it should be ascertained that the conditions of pasteurization have been observed and that the plant is of the proper type in which, for example, it is impossible for the raw milk to reach the pasteurized milk.

But holder pasteurization is, I believe, in the course of being superseded by the high temperature short time process. The new Milk (Special Designations) Regulations, 1941, permit (provisionally) heating milk at not less than 162° F. for not less than 15 seconds. Theoretically a temperature of about 162° F. for 15 seconds should have the same lethal effect on organisms as 144° F. for 25 minutes. But this is a continuous flow process and the time of heating to the holding temperature is perhaps even more important than in Holder pasteurization, since its duration above 140° F. is a considerable proportion of the total time in the range lethal for pathogenic organisms. The fact that the process is one of continuous flow makes laboratory experiments, faithfully reproducing practical conditions, very difficult, and I have not as yet seen any published work that is beyond criticism in this respect. The practical evidence for the destruction of tubercle bacilli is, I think, convincing, but not as yet extensive. A considerable body of American work points to the conclusion that 160° F. for 15 to 16 seconds is satisfactory, and some recent experiments of a colleague and myself[3] indicate that the temperature/time requirements of the Provisional Regulations allow a margin of safety. This process is very attractive for many reasons but it will have to be carefully controlled. We have recently found, in work with the National Physical Laboratory, that the thermometric apparatus, translated from holder plants, may lack that speed of response to changes in temperature which I believe to be essential in some continuous-flow processes. We have found that thermo-couples are admirable for the purpose, and I hope to see them universally adopted.

For ensuring the destruction of pathogenic organisms and for avoiding later contamination, the "in-bottle" process of pasteurization has much to recommend it, but my personal knowledge *is* insufficient to discuss it from the practical and economic viewpoints.

Steam injection process—The importance of protecting farm stock from infection has been referred to earlier. Calves and pigs are notoriously susceptible to infection by bovine tubercle bacilli in milk, whey, skim milk and other by-products. A cheap and effective process of pasteurization suitable for treating by-products before dispatch to the farm was tested by us 3 or 4 years ago.[8] It embodies a controlled method of steam injection into the product and was found to be effective at 175° F. for 3 seconds. It was also found that bovine tubercle bacilli added in very large numbers were complete destroyed. The dilution resulting from steam injection is of no account in stock feeding and I should welcome a complete official ban on the distribution of infected milk or milk products to animals, from creameries and factories.

Brucella abortus—My own experience, like that of others, shows that this organism is more frequently present in bulk milk than is generally realized, and I need not refer to the literature on the incidence of cases of undulant fever in man. I am convinced that they are far more frequent than these figures show owing to failure to recognize the condition and to make proper confirmatory diagnoses by bacteriological methods. All that need be said is that the organism has no great heat resistance and that there is no evidence of its recovery from properly pasteurized milk.

Streptococci pathogenic for man—Similarly it need only be stated that the strains known to infect man are easily destroyed by heat, and so far as I am aware have never been found to survive correct pasteurization.

Staphylococci—These organisms are far more common in raw milk than has been appreciated in the past. They occur in the udders of very many milking cows (Shattock[9]). They are more heat resistant than most other pathogenic organisms although their infectivity by the mouth may be small or non-existent. In examining a large number of samples from commercial plants working at about 145° F. for 30 minutes I have not yet encountered these organisms in the uncontaminated milk, although they certainly may survive 140° F. for 30 minutes. Their importance in uncontaminated pasteurized milk does not seem to me to be great. Some strains, however, if allowed unrestricted growth in milk, produce entero-toxins which have unfortunate, though normally only temporary, effects on the individual. The situation regarding the common pathogenic organisms infective by the mouth may be summarized by saying that the evidence from the academic and practical aspects leaves no reasonable doubt that after heating at 145° F. for 30 minutes bulk milk may be consumed without danger of infection. It will, however, be obvious that all the steps necessary to preclude after-contamination must be taken. The evidence so far adduced refers only to the milk as it leaves the efficient plant, and to complete the account it is necessary to consider that part of the raw milk flora which is usually held to be non-pathogenic, and to review the possible sequelae of pasteurization in respect of organisms of this type. It was once widely held, and the belief still has its adherents, that "within reason" (not defined) milk of any hygienic quality was suitable for pasteurization. Fortunately the belief is disappearing, for, as I hope to show, it is quite untenable.

In considering the bacteriology of pasteurization it is, therefore, necessary to begin with the raw milk. The flora of the healthy udder is small in numbers and qualitatively simple; it appears that if the total plate count of the fresh milk exceeds 200 per ml. (in most cases 300 per ml.) there is an infection of the udder.[10] Gibson and Abdel-Malek[11] showed in a careful examination of a small number of aseptically drawn samples from healthy animals that the only organisms present were micrococci and *Corynebacterium sp.*, and Shattock[12] has also found in examining a very large number of samples for other purposes that these organisms either separately or together are almost invariably the only flora. Gibson and Abdel-Malek also found that neither of these organisms survived in milk heated to 63° C. for 30 minutes and their evidence questions a body of American opinion that the micrococci of commercial pasteurized milk are directly derived, at least in part, from the udder of the cow. Davis *et al.*[13] have observed that if ordinary fresh milk is laboratory pasteurized at 63° C. for 30 minutes and held at 34° F. it will keep without significant change for about 30 days.

The fact is that milk from healthy cows without adventitious contamination is virtually sterilized by pasteurization. But, unfortunately, not all udders are healthy and streptococci, mainly *Streptococcus agalactiae*, *Str. uberis*, and *Str. dysgalactiae* with other streptococci less certainly pathogenic, either for man or animals, together with staphylococci, may be added to the micrococci and *Corynebacterium* of the healthy udder. Moreover, in the course of milking, however careful, under practical conditions, other organisms gain access to the milk in variable numbers. Thus in certified raw milks, Gibson and Abdel-Malek[11] found that streptococci and micrococci predominated. *Corynebacteria* were frequent and variable in numbers and other organisms occurred only to a small extent. After pasteurization the streptococci disappeared, showing that those present in the raw milk were mainly of pathogenic types which are acknowledged to be destroyed by pasteurization in milk. The preponderating survivors were *Corynebacterium* but of a type different from those of the udder, which are not heat resistant. They grow poorly or not at all above 30° C., are heat resistant and were described by Orla Jensen[14] as *Microbacterium lacticum*. Few micrococci were found to survive pasteurization and the results, in general, show that the organisms in cleanly but not aseptically taken milk are vulnerable to pasteurization. The results were different with milk from tankers, in that after pasteurization streptococci predominated, followed in numbers by *Corynebacterium* and micrococci. Other organisms were either absent or present in minimal numbers, although *Pseudomonas* was found in some raw samples.

These *in vitro* experiments are valuable in that they indicate the great influence of the conditions of production and handling of the raw milk on the flora of the pasteurized milk and emphasize the fact that there is no danger from the udder flora of the healthy cow, a conclusion of some significance.

The flora of raw milk as it reaches the plant after production at the farm under conditions often far from ideal may be quantitatively large and qualitatively varied. Amongst the organisms surviving pasteurization in the largest numbers are the so-called thermoduric cocci. Several factors determine the heat resistance of any organism but there is much evidence that bad conditions of production at the farm, such as failure to sterilize utensils and milking machines, coupled with uncleanly milking methods, result in the survival of large numbers of organisms, so that there is nothing like the complete destruction recorded for aseptically taken milk. The survivors are streptococci, micrococci and spore formers of several types. Their survival is also related to the previous history of the milk in respect of age and temperature. The streptococci are of the *Str. lactis* and *Str. faecalis* types derived ultimately from souring milk residues, from the skin of the cow's udder and teats and from cow dung.[15] Their actual heat resistance, like that of many organisms, is related to their immediate previous history. Their main activity in milk is acid formation; when numbers are appreciable they cause premature souring. The micrococci, sometimes present in relatively large numbers in freshly pasteurized milk, are usually slow acid formers growing over a wide range of temperature, but they may have proteolytic properties as well.

The aerobic spore formers are very commonly present in pasteurized milk, usually in small numbers that are proportionately greater in winter than in summer. It appears that the shock of heating induces germination in spores which would otherwise remain dormant, and when the flora of pasteurized milk is much simplified they may cause rapid spoilage. In recent years "broken or bitty cream" and "sweet curdling" rennin type of coagulation have often occurred in warm weather in pasteurized milk.

Coliform organisms, so useful as an index of proper plant management in *freshly* pasteurized milk, normally survive in very small numbers if at all, but it appears that occasional types, derived, for example, from dirty milking machines, may be heat resistant at least in the first generation. They may survive more frequently in foam on the holding vats and in this respect the H.T.S.T. process has the advantage. The presence of heat resistant organisms in the raw milk detracts from the value of the plate count as an official measure of efficient pasteurization and I consider it of very doubtful value for this purpose.

Plant contamination—Unless pasteurizing plants are properly constructed and run, it is true to say that the final product may contain more organisms, often of course innocuous, than the original raw milk. This is due to the growth of thermophilic types growing at 55° C., as in the regenerator, or at 63° C., as in the holder. The former are usually streptococci or aerobic spore bearers, the latter usually aerobic spore bearers. I have observed several times milk that has had a keeping quality of only a few hours owing to the growth in the vats of thermophilic spore bearers. The remedy is to avoid dead ends, to keep the plant scrupulously clean and to shun runs of more than, say, 4½ hours' duration. My own experience of H.T.S.T. plants[16] is that difficulties caused by thermophils are much fewer than in Holder plants, for the temperature of heating destroys vegetative forms from the regenerative section and prevents great accumulations. Moreover, the temperature is above that normally favourable for most thermophilic organisms. It may be of interest that we have found thermophilic organisms to be remarkably susceptible to light, a short exposure to weak daylight almost sterilizing plates made to enumerate them.[17]

Post-pasteurization contamination—After milk has left the pasteurizer with its flora greatly reduced and normally much simplified, it is important to consider the role of pipes, storage vats, bottle fillers, capping machines and bottles. These are often difficult, and not infrequently at present almost impossible, to sterilize, and are liable to be neglected. Neglect is not likely to impair the safety of the milk, but its keeping quality will certainly suffer. Acid-producing cocci, *Proteus* and coliform types are common, and after-contamination greatly reduces keeping quality. Even with the present raw milk supply, the milk from the holder will keep for some 42 hours to 48 hours at 70° C. or for 3½ days at 60° F. Over a period of 4 years 95 per cent. of milk samples taken from roundsmen's bottles after passing through a well-run plant kept for at least 2½ days at 60° F. Bottles above all must be properly sterilized, since as they are returned from consumers' houses they are potentially dangerous. It is true that the main trouble is from non-pathogenic types, but my opinion is that there is much room for improvement in the design of bottle fillers and bottle washers. A really satisfactory form of the latter remains to be produced, to avoid contamination of the final rinse water—a formidable source of trouble. Suggestions for their improvement have recently been made by several workers but others might well apply themselves to this important task. The consumer has only one thing to do—treat the milk reasonably and intelligently and keep it cool and in the dark. This is unfortunately a weak link in the chain; but even so, without pasteurization there would be little or no liquid milk in the great towns at present. I would like to make one final point. Evidence is accumulating that when organisms previously regarded as harmless are present in milk in large numbers they may produce irritant substances affecting the consumer. There is no need for milk at any stage of its life before delivery to contain more than minimal numbers and we should bear this fact in mind and act on it in all its implications. This may mean the setting up of standard methods of control at all stages.

What then may be concluded from the facts given in this rapid survey? First, that in properly controlled pasteurization we have a method of rendering the milk supply safe for the consumption of the mass of the people. Second, that under present conditions pasteurization enhances the keeping quality of milk and makes it possible for milk to be generally distributed. Third, that with improved methods of raw milk production and control, coupled with improvements in the apparatus and technique of manipulation of the milk after the actual heating process, together with improved methods of distribution and conservation in the home, we have the possibility of furnishing the people with a product of such superb quality as is at present visualized only by the few. To the opponents of compulsory pasteurization we may say with David "An unwise man doth not well consider this: and a fool doth not understand it."

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THE REST OF OUR DIET

AN EDITORIAL POSTSCRIPT

The seven foods or groups of foods discussed in the twenty-seven chapters of this book include all those that in quantity of nutrients account for the major portion of the diets normally eaten in the British Isles. Yet there are certain other "comestibles"—foods, condiments and beverages—that have their place in the national bill-of-fare, not only as contributions to its variety and enjoyment, but also as supplementary sources of essential nutrients. They fall into a small number of fairly well-defined, or definable, groups, namely, cane sugar and "sweets"; tea and coffee; cocoa and chocolate; yeast and the products of alcoholic fermentation, beer, wine and spirits; meat extracts; nuts and fruits; preserves and honey; vinegar and condiments. The FOOD GROUP is aware of the need to give to these substances, in proportion to their nutritive importance, a treatment similar to what in this book has been afforded the main foods of the nation. With this end in view the Committee of the Group, on the recommendation of its NUTRITION PANEL, has agreed to hold in the near future meetings at which short papers will be delivered on each of the topics mentioned. Should the welcome given to this book justify, as we trust it may, the appearance of a second edition in the near future, these additional papers may well appear in it as a final chapter, in place of this Postscript, which we recognise to be at least as much an apology as a justification. The conditions of war-time and the period following it have, however, made it impossible before now to take these steps, recognised by us as much as by anyone to be necessary if "The Nation's Food" is to fulfil the promise implicit in its title.

THE EDITORS

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